

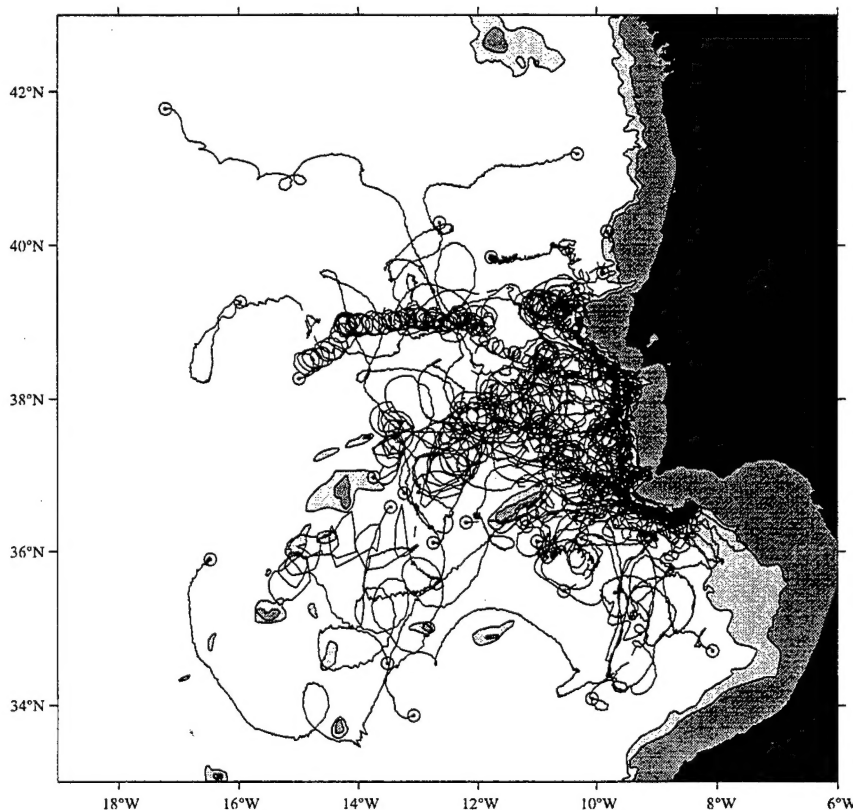
# **A Mediterranean Undercurrent Seeding Experiment (AMUSE):**

## **Part II: RAFOS Float Data Report May 1993 - March 1995**

by

Heather D. Hunt, Christine M. Wooding, Cynthia L. Chandler,  
and Amy S. Bower

June 1998



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**Woods Hole Oceanographic Institution  
Technical Report  
WHOI-98-14**

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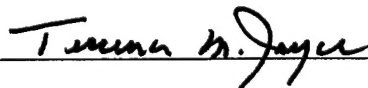
**Technical Report**

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Terrence M. Joyce, Chairman  
Department of Physical Oceanography

## Abstract

This is the final data report of all acoustically tracked RAFOS data collected in 1993-1995 during A Mediterranean Undercurrent Seeding Experiment (AMUSE). The overall objective of the program was to observe directly the spreading pathways by which Mediterranean Water enters the North Atlantic. This includes the direct observation of Mediterranean eddies (meddies), which is one mechanism that transports Mediterranean Water to the North Atlantic. The experiment was comprised of a repeated high-resolution expendable bathythermograph (XBT) section and RAFOS float deployments across the Mediterranean Undercurrent south of Portugal near  $8.5^{\circ}\text{W}$ . A total of 49 floats were deployed at a rate of about two floats per week on 23 cruises on the chartered Portuguese-based vessel, Kialoa II, and one cruise on the R/V Endeavor. The floats were ballasted for 1100 or 1200 decibars (db) to seed the lower salinity core of the Mediterranean Undercurrent. The objectives of the Lagrangian float study were (1) to identify where meddies form, (2) to make the first direct estimate of meddy formation frequency, (3) to estimate the fraction of time meddies are being formed, and (4) to determine the pathways by which Mediterranean Water which is not trapped in meddies enters the North Atlantic.

**Front Cover Figure Caption:** “Spaghetti” diagram showing the AMUSE float tracks. The floats were launched south of Portugal, at about 36.6°N 8.4°W, to seed the Mediterranean Undercurrent. Untrackable float segments are represented as dashed lines; ‘out of the page’ symbols mark the surface positions. The 1000 and 2000 meter isobaths are shaded in gray.



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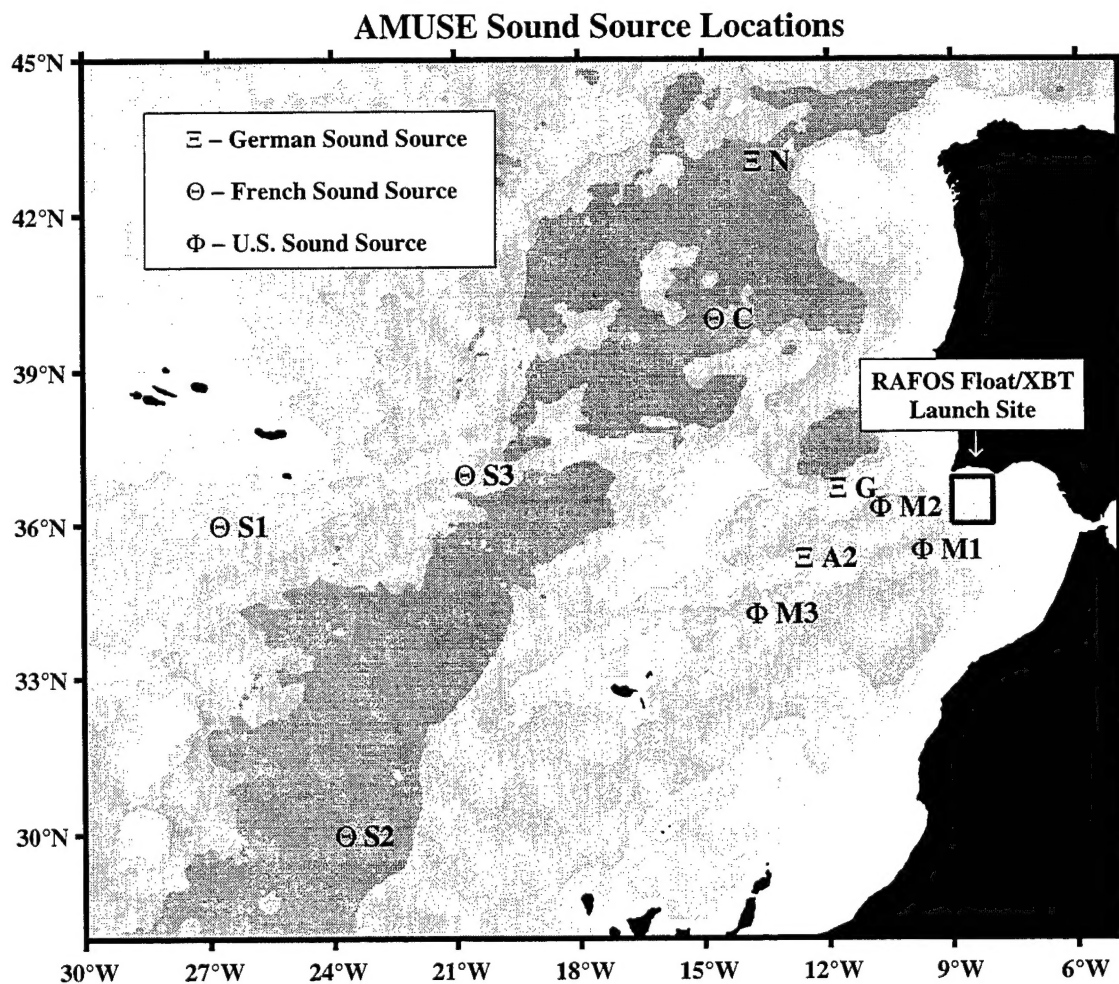
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## 1. Introduction

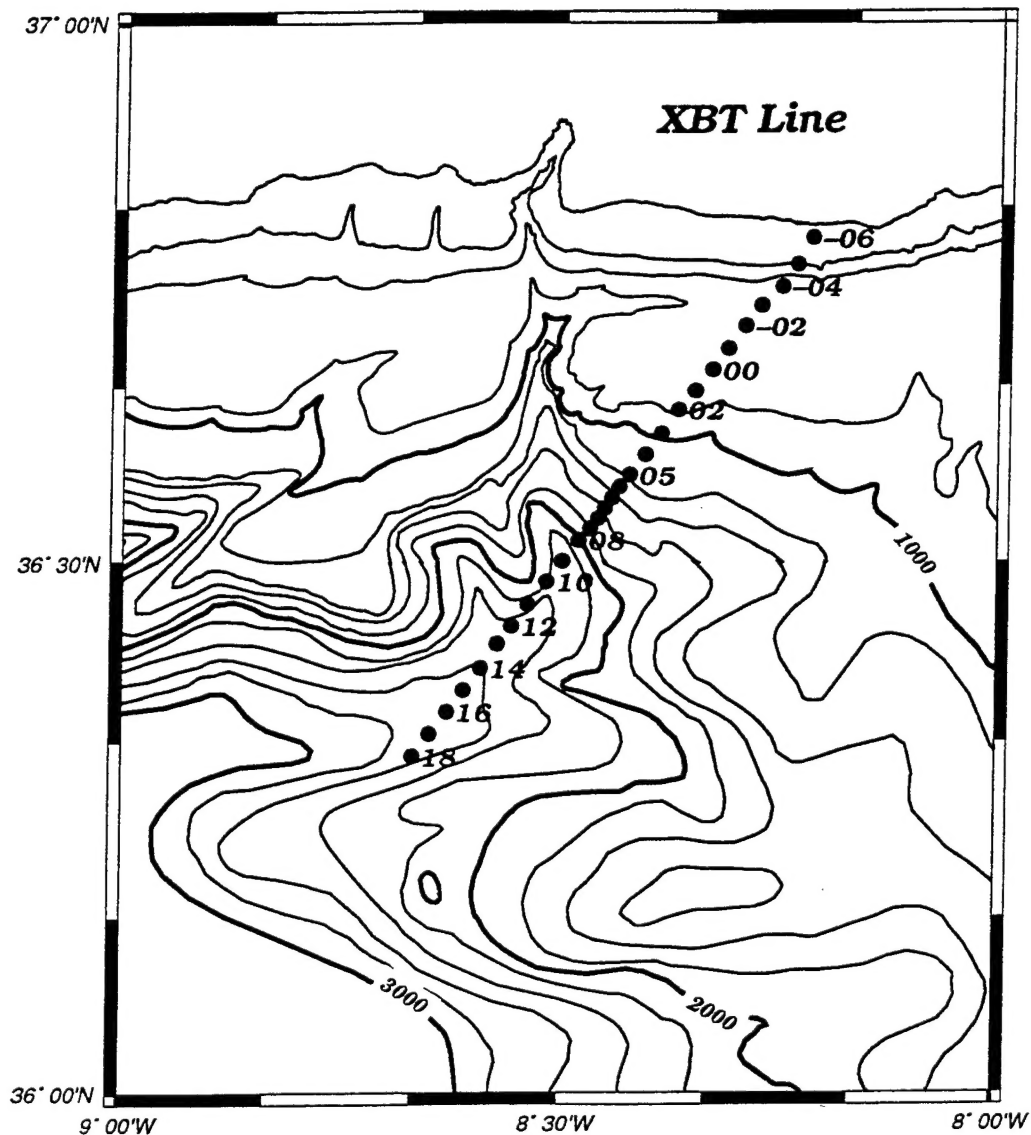
This is the final data report of all acoustically tracked Ranging and Fixing of Sound (RAFOS) float data collected in 1993-1995 during A Mediterranean Undercurrent Seeding Experiment (AMUSE). Principal investigators for the project were Amy Bower of the Woods Hole Oceanographic Institution, Laurence Armi of the Scripps Institution of Oceanography, and Isabel Ambar of the University of Lisbon. The overall objective of the program, funded by the National Science Foundation and by the Luso-American Foundation for Development (FLAD), was to observe directly the spreading pathways by which Mediterranean Water enters the North Atlantic. This includes the direct observation of Mediterranean eddies (meddies), which is one mechanism that transports Mediterranean Water into the North Atlantic. The experiment was comprised of high-resolution expendable bathythermograph (XBT) and RAFOS float deployments in a



**Figure 1:** AMUSE float and XBT deployment and sound source locations in the eastern North Atlantic. Bathymetry intervals are every 1000 meters, shown by different shades of gray.

section across the Mediterranean Undercurrent south of Portugal (see Figure 1 and Figure 2). The objectives of the Lagrangian float study were (1) to identify where meddies form, (2) to make the first direct estimate of meddy formation frequency, (3) to estimate the fraction of time meddies are being formed, and (4) to determine the pathways by which Mediterranean Water which is not trapped in meddies enters the North Atlantic.

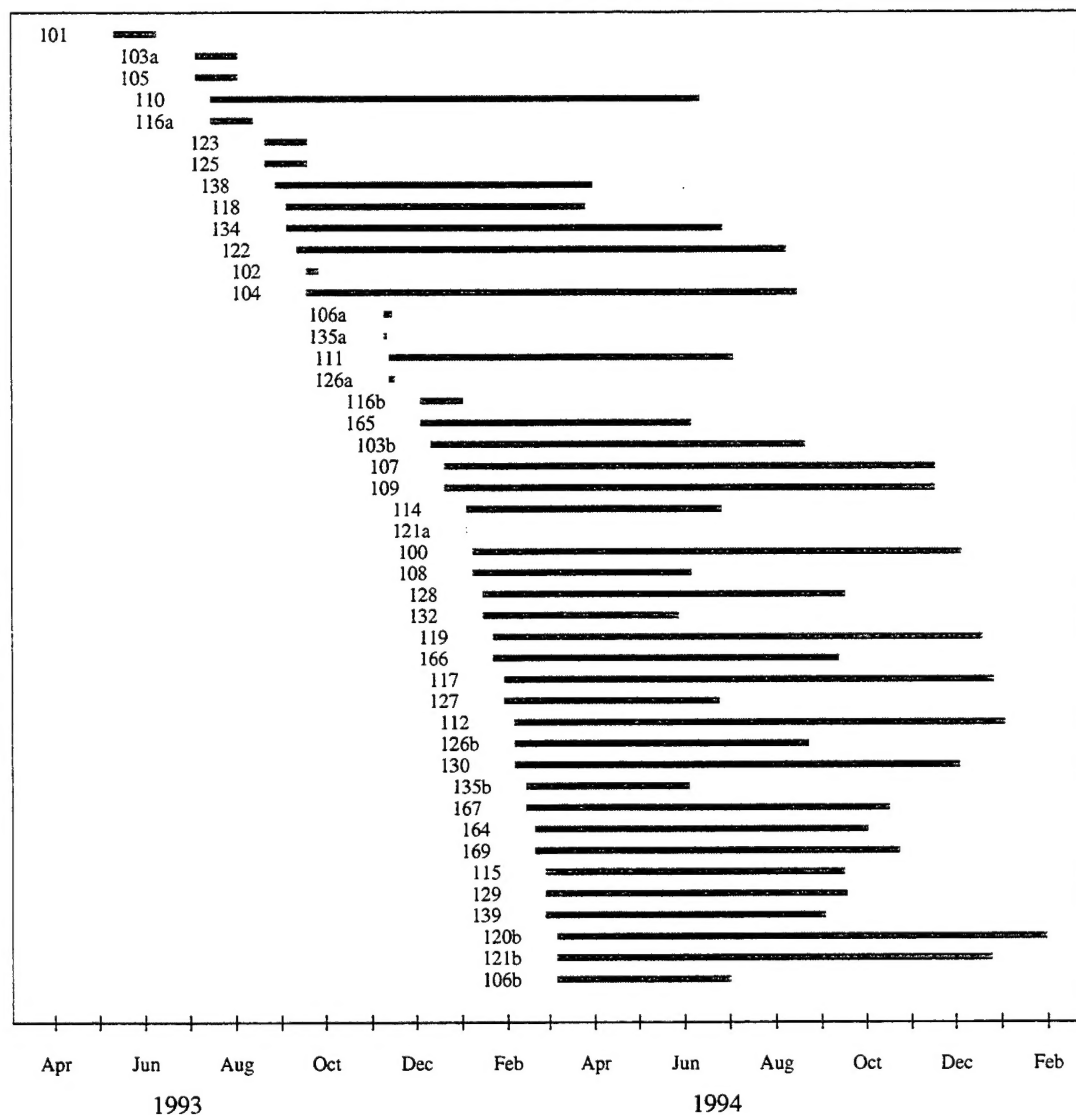
The Mediterranean Undercurrent is comprised of two salinity maxima. The deeper salinity core was chosen as the target for the float seeding since the water from this core is found in almost all meddies, while water from the upper core is found in only some meddies.



**Figure 2:** An expanded view of the float and XBT launch site, shown in Figure 1. The black dots mark where the XBTs were deployed. Floats were launched between XBT launch locations 05 and 08. Bathymetric contours are shown every 200 meters.

The first two floats were launched from the R/V Oceanus in May 1993 during a preliminary CTD survey of the Undercurrent south of Portugal aimed at finding the best float launch site for the repeated seeding. Forty-seven floats were subsequently deployed at a rate of about two floats per week on 22 of 24 cruises of the Portuguese-based chartered vessel Kialoa II between July 1993 and March 1994 (see Figure 3 and Table 1). The floats were ballasted for 1100 or 1200 decibars (db). They were programmed for up to 11-month missions, and tracked using seven moored sound sources. Three of the sources were deployed specifically for AMUSE from the R/V Oceanus in May 1993, and the others had been deployed by German and French scientists for other experiments.

**AMUSE Float Duration Chart**



**Figure 3:** Float duration chart showing the periods that the floats were in the water. Float numbers are marked on the left. Floats are listed in order of launch date from top to bottom.

## 2. Description of the RAFOS Floats

The RAFOS float is an acoustically tracked subsurface Lagrangian drifter (see Rossby *et al.* (1986) for a complete description of the RAFOS system), which is programmed to listen for signals from moored sound sources. The RAFOS float determines the time-of-arrival (TOA) of these signals, from which, given the speed of sound in water, its position can be determined. The TOA of the acoustic signals, as well as temperature and pressure measurements are stored in the float's micro-processor memory. Also stored in the float's memory are correlation heights for each TOA, which indicate the quality of the TOA signal heard. The sound sources in this experiment were programmed to transmit an 80 second long continuous wave tone, which linearly increases its frequency from 259.375 Hz to 260.898 Hz. The individual sound sources broadcast this tone three times a day, and broadcast at different times (beginning at 0030, 0100, and 0130 UTC, and every eight hours thereafter). The floats in this experiment listened for these signals once every eight hours (beginning at 0025 UTC). The float temperature sensors were built by Yellow Springs Instrument Company and were calibrated to  $\pm 0.01^{\circ}\text{C}$ . These thermistors were mounted on the main float board and logged manually. Float pressure sensors were built by Data Instruments and calibrated to  $\pm 1\%$  at 2000 psi.

**Table 1. RAFOS Float Summary – launch and surface data**

| Float ID | Launch Site | LAUNCH         |                                 |                                  | SURFACE        |                                 |                                  | Length of Mission (days) |
|----------|-------------|----------------|---------------------------------|----------------------------------|----------------|---------------------------------|----------------------------------|--------------------------|
|          |             | Date (yyymmdd) | Latitude ( $^{\circ}\text{N}$ ) | Longitude ( $^{\circ}\text{W}$ ) | Date (yyymmdd) | Latitude ( $^{\circ}\text{N}$ ) | Longitude ( $^{\circ}\text{W}$ ) |                          |
| 101      | OCctd110    | 930511         | 36.556                          | 8.438                            | 930610         | 37.692                          | 10.064                           | 30                       |
| 113      | OCctd111    | 930511         | 36.536                          | 8.458                            | 930512         | 36.533                          | 8.447                            | 1                        |
| 103a     | K0106       | 930705         | 36.561                          | 8.442                            | 930804         | 36.276                          | 11.179                           | 30                       |
| 105      | K0107       | 930705         | 36.539                          | 8.462                            | 930804         | 37.636                          | 11.675                           | 30                       |
| 110      | K0207A      | 930715         | 36.525                          | 8.480                            | 940613         | 38.014                          | 15.150                           | 333                      |
| 116a     | K0205       | 930715         | 36.577                          | 8.429                            | 930814         | 37.621                          | 11.516                           | 30                       |
| 123      | K0306       | 930821         | 36.564                          | 8.442                            | 930920         | 36.524                          | 8.340                            | 30                       |
| 125      | K0307       | 930821         | 36.542                          | 8.460                            | 930920         | 37.085                          | 9.385                            | 30                       |
| 124      | K0405A      | 930828         | 36.571                          | 8.432                            | no show        |                                 |                                  |                          |
| 138      | K0407       | 930828         | 36.540                          | 8.465                            | 940401         | 39.623                          | 9.912                            | 216                      |
| 118      | K0506       | 930904         | 36.561                          | 8.443                            | 940327         | 39.654                          | 12.967                           | 204                      |
| 134      | K0507       | 930904         | 36.542                          | 8.460                            | 940628         | 36.686                          | 13.435                           | 297                      |
| 120a     | K0606A      | 930911         | 36.549                          | 8.453                            | 930914         | 36.498                          | 8.827                            | 3                        |
| 122      | K0607A      | 930911         | 36.533                          | 8.471                            | 940810         | 37.891                          | 12.311                           | 333                      |
| 102      | K0706       | 930918         | 36.561                          | 8.446                            | 930928         | 36.965                          | 9.850                            | 10                       |
| 104      | K0707A      | 930918         | 36.531                          | 8.471                            | 940817         | 40.481                          | 9.856                            | 333                      |
| 106a     | K0906       | 931109         | 36.562                          | 8.446                            | 931116         | 36.689                          | 9.313                            | 6                        |
| 135a     | K0907A      | 931109         | 36.532                          | 8.470                            | 933113         | 36.476                          | 8.566                            | 5                        |

**Table 1. RAFOS Float Summary (continued)**

| Float ID | Launch Site | LAUNCH         |               |                | SURFACE        |               |                | Length of Mission (days) |
|----------|-------------|----------------|---------------|----------------|----------------|---------------|----------------|--------------------------|
|          |             | Date (yyymmdd) | Latitude (°N) | Longitude (°W) | Date (yyymmdd) | Latitude (°N) | Longitude (°W) |                          |
| 111      | K1006       | 931113         | 36.561        | 8.444          | 940705         | 35.209        | 10.266         | 235                      |
| 126a     | K1007       | 931113         | 36.542        | 8.463          | 931118         | 36.490        | 8.558          | 5                        |
| 116b     | K1205A      | 931204         | 36.572        | 8.437          | 940103         | 36.963        | 10.101         | 30                       |
| 165      | K1208       | 931204         | 36.522        | 8.482          | 940607         | 38.106        | 10.689         | 185                      |
| 103b     | K1306       | 931211         | 36.563        | 8.445          | 940822         | 37.663        | 11.103         | 254                      |
| 170      | K1307A      | 931211         | 36.531        | 8.470          | 940905         | 33.010        | 19.273         | 269                      |
| 107      | K1406       | 931220         | 36.562        | 8.444          | 941118         | 35.924        | 10.894         | 333                      |
| 109      | K1407A      | 931220         | 36.532        | 8.471          | 941118         | 41.803        | 17.204         | 333                      |
| 114      | K1505A      | 940104         | 36.572        | 8.434          | 940627         | 39.210        | 10.223         | 174                      |
| 121a     | K1506A      | 940104         | 36.551        | 8.453          | 940106         | 36.481        | 8.737          | 3                        |
| 100      | K1606       | 940108         | 36.561        | 8.445          | 941206         | 34.032        | 10.156         | 333                      |
| 108      | K1608       | 940108         | 36.521        | 8.480          | 940607         | 36.135        | 11.081         | 151                      |
| 128      | K1705A      | 940115         | 36.568        | 8.435          | 940918         | 40.340        | 12.760         | 246                      |
| 132      | K1706A      | 940115         | 36.550        | 8.452          | 940529         | 36.377        | 12.197         | 134                      |
| 119      | K1806A      | 940122         | 36.549        | 8.454          | 941220         | 41.272        | 10.487         | 333                      |
| 166      | K1807A      | 940122         | 36.531        | 8.470          | 940914         | 35.622        | 12.707         | 245                      |
| 117      | K1905A      | 940129         | 36.573        | 8.434          | 941228         | 39.351        | 15.716         | 333                      |
| 127      | K1907A      | 940129         | 36.534        | 8.472          | 940625         | 39.968        | 9.977          | 148                      |
| 112      | K2005A      | 940205         | 36.571        | 8.433          | 950104         | 36.007        | 16.478         | 333                      |
| 126b     | K2006A      | 940205         | 36.551        | 8.453          | 940824         | 36.666        | 13.236         | 201                      |
| 130      | K2007A      | 940205         | 36.530        | 8.471          | 941205         | 38.648        | 11.350         | 303                      |
| 135b     | K2105A      | 940213         | 36.570        | 8.434          | 940605         | 39.229        | 10.288         | 112                      |
| 167      | K2106A      | 940213         | 36.560        | 8.443          | 941018         | 39.312        | 11.057         | 247                      |
| 164      | K2205A      | 940219         | 36.572        | 8.434          | 941003         | 36.149        | 10.317         | 226                      |
| 169      | K2207       | 940219         | 36.541        | 8.460          | 941025         | 33.889        | 13.091         | 249                      |
| 115      | K2305A      | 940226         | 36.572        | 8.435          | 940917         | 34.373        | 13.501         | 203                      |
| 129      | K2307A      | 940226         | 36.532        | 8.467          | 940919         | 36.874        | 13.427         | 206                      |
| 139      | K2307       | 940226         | 36.542        | 8.460          | 940904         | 36.116        | 12.780         | 190                      |
| 120b     | K2406       | 940305         | 36.562        | 8.444          | 950201         | 37.881        | 12.102         | 333                      |
| 121b     | K2406A      | 940305         | 36.552        | 8.452          | 941226         | 35.022        | 7.555          | 297                      |
| 106b     | K2407       | 940305         | 36.542        | 8.461          | 940702         | 37.695        | 12.598         | 119                      |

The RAFOS float electronics were built by Sea Scan, Inc. The WHOI float group (Jim Valdes, Bob Tavares, and Brian Guest) assembled the floats and ballasted them in the ballasting tank at Webb Research Corporation. A few floats were ballasted by the WHOI float group at the University of Rhode Island for comparison purposes. Isobaric floats were initially ballasted with a hollow drop weight that forces the floats to be neutrally buoyant at a desired pressure surface. More detail on the ballasting procedure

can be found in the report by Anderson-Fontana *et al.*, 1996. It became apparent, after several floats sank, registered overpressure, and then surfaced early, that the hollow drop weights were susceptible to leaking and corrosion. The hollow weights were replaced early in the field program with solid drop weights, solving these problems. The floats were placed in the Mediterranean Undercurrent off Cape St. Vincent to follow the 1100 or 1200 db pressure surface.

After the float completes its mission, it is programmed to drop its external ballast, rise to the ocean surface, and telemeter its data to Service Argos receivers aboard the NOAA Polar Orbiting Environmental Satellites. Through Service Argos, the data are relayed to a ground station and transferred to a Global Processing Center. There, the data are processed and then transferred via the Internet to WHOI. The raw float data, including temperature, pressure, TOAs and respective correlations, are converted from hexadecimal to decimal, and are then ready for advanced processing, editing, and tracking.

### **3. Sound Source Deployment**

Seven sound sources were used to track the AMUSE floats (locations shown in Figure 1). Three of these (M1-M3) were deployed specifically for AMUSE during the May 1993 CTD survey. Their placement was designed to provide maximal coverage along the south coast of Portugal and around Cape St. Vincent, a potential site of meddy formation and float dispersal. The other four sources, deployed by IFREMER (C) and IfM/Kiel (N, G, A2) for other experiments provided valuable coverage once the AMUSE floats moved away from the continental slope and into the Iberian Basin. The relatively large number of sources was needed to minimize topographic shadowing due to the rugged Horseshoe Seamounts and the Estremadura Promontory.

The vital statistics for each source are given in Table 2. All the sources were built by Webb Research Corporation and signaled every eight hours, beginning at 00:30, 01:00, 01:30, or 01:32 (pong times). Two sources, M3 and G, had clock failures within a year of activation. The clock of sound source N jumped 16 seconds 20 months after activation.

### **4. Float Deployment**

To choose a suitable launch site for the floats, the seeding experiment was preceded by a detailed CTD survey of the Undercurrent in the western Gulf of Cadiz in May, 1993 from the R/V Oceanus OC258 (Bower *et al.*, 1997). In choosing a float deployment site, we tried to balance three basic criteria. The launch site had to be (1) downstream of the region in the eastern Gulf of Cadiz where the Mediterranean Water is being carried in a bottom-trapped gravity current; (2) upstream of all potential meddy formation sites that had been suggested in the literature; and (3) close to a suitable port for easy access. Based on the results of the CTD survey, a site was chosen south of Portugal in Portimao Canyon near 36° 30'N, 8° 00'W (Figures 1 and 2). To launch floats and XBTs on a weekly basis,



Table 2. Sound Source Moorings

| Source Site & No. | Pong Time (GMT) | Launch Date (yyymmdd) | Recovery Date (yyymmdd) | Depth (meters) | Latitude (°W) | Longitude (°N) | Drift Rate (seconds/day) | Comments               |
|-------------------|-----------------|-----------------------|-------------------------|----------------|---------------|----------------|--------------------------|------------------------|
| M1, 01            | 00:30           | 930503                |                         | 1500           | 35.505        | 10.000         | 0                        |                        |
| M2, 02            | 01:30           | 930502                |                         | 1500           | 36.334        | 11.000         | 0                        |                        |
| M3, 03            | 01:32           | 930501                |                         | 1500           | 34.263        | 13.991         | 0*                       | Clock failed on 930926 |
| N, 04             | 00:30           | 930101                | 940900                  | 800            | 43.027        | 14.015         | 0                        | +16 sec on 940328      |
| A2, 05            | 01:00           | 930101                | 940900                  | 800            | 35.349        | 12.808         | 0                        |                        |
| G, 06             | 01:00           | 930101                |                         | 800            | 36.707        | 11.988         | 0*                       | Clock failed on 931215 |
| C, 07             | 01:30           | 930101                | 940501                  | 1500           | 40.008        | 14.993         | 0                        |                        |

\* Drift rates for these sources are unknown, and assumed zero for this experiment.

it was necessary to engage the services of a chartered vessel because conventional research vessels could not accommodate this type of schedule. The 72-foot motor-sailing yacht Kialoa II, owned and operated by Dr. Frank Robben, was chartered for the experiment, and the port of Vilamoura, on the south coast of Portugal, was chosen as the base of operations. Rita Klabacha from Scripps Institution of Oceanography managed the operations in Vilamoura and on the float/XBT deployment cruises on board Kialoa II. She was assisted by members of the Oceanography Group at the University of Lisbon.

The float observational strategy was to survey the Undercurrent with XBTs along a section perpendicular to the slope (Figure 2), and launch a pair of floats in the deeper of the two salinity maxima in the Undercurrent every week. The time between float seedings was chosen to be slightly shorter than the indirect estimate of the time for a typical meddy to form of 10-20 days (Armi and Zenk, 1984). The floats were initially ballasted for 1100 db to seed the lower salinity core, but the first XBT profiles showed that the highest temperatures associated with this core were found at 1200 db, so the target pressure was changed shortly into the float seeding experiment.

The deployment plan called for the release of 40 floats on 20 cruises made once a week for five months. A number of technical problems with the floats forced us to make several breaks in the weekly deployment strategy (see Table 1 and Figure 3). Some floats were recovered to help diagnose the technical problems (explained in the next section), and these floats were refurbished and deployed for a second mission. These floats are

indicated by 'a' and 'b' in Table 1. As a result, we made a total of 49 float deployments on 22 Kialoa cruises and one Oceanus cruise between May, 1993 and March, 1994. Ten floats were programmed for a 30-day mission, 38 for a 333-day (11-month) mission, and one float for a 119-day mission. The 30-day float missions were set so that the float and sound source performance could be checked early in the experiment. The 119-day mission was set to test the performance of a new seal on the end cap of the glass float housing. All floats were programmed to collect temperature, pressure and acoustic tracking data every eight hours.

## **5. Float Performance**

Table 1 lists the launch and surface data for each float, as well as the actual length of each float's mission, and Table 3 documents the technical performance of each float. Two main problems led to the premature surfacing of many of the floats: sinking caused by a leak in the glass housing or the hollow drop weight, which caused the floats to release their ballast weight and surface (eight floats), and unexplained loss of the ballast weight, probably due to fishbite or corrosion (21 floats). The first problem was corrected early in the experiment by replacing the hollow weights with solid stainless steel and removing the hardcoat from the aluminum endplate (thought to be compromising the glued seal). The cause (and cure) of the second problem was never determined, although some recovered floats showed significant corrosion of the endplate, suggesting that may have been a factor. Also, no floats lost their weights unexpectedly until they had been in the water for at least three months, which would not be consistent with fishbite (should be more random). Floats that surfaced early still transmitted the data they had collected up to that point. In addition to these two failure modes, one float surfaced early due to low battery voltage and one float never surfaced and/or transmitted any data. Eighteen of the 49 floats completed their missions.

In spite of these technical problems, 48 of the 49 floats launched returned to the surface, and 44 floats returned some useful data. Of the five floats that returned no useful data, two sank and surfaced within two days, one did not surface/transmit, one returned corrupted data, and one returned pressure and temperature data but no tracking data. Of the 48 floats that returned to the surface, the average percent of the mission accomplished was 70%.

## **6. Float Data Processing and Tracking**

Service Argos satellites received the transmissions of the RAFOS floats and Service Argos forwarded them to WHOI via FTP. The floats transmitted the data in random order so that the entire mission of the float would be represented even if the float stopped transmitting before all the data messages were received. The messages were put in order, converted from hexadecimal to decimal, and the times-of-arrival (TOAs), correlation heights, temperatures and pressures were extracted. At this stage, the temperatures and pressures were converted from counts to engineering units, using the coefficients in Table

4 and the algorithms described below. The clock-drift of the float was calculated at this step by averaging the difference between the expected and actual reception times (using the Argos clock) of up to 25 messages received in the first twelve hours.

Table 3. Float Performance

| Float ID | % Mission Completed | % Messages Received | Temp Corrected (Y/N) | Pressure (db) |         |         | Comments                              |
|----------|---------------------|---------------------|----------------------|---------------|---------|---------|---------------------------------------|
|          |                     |                     |                      | Mean          | Minimum | Maximum |                                       |
| 101      | 100                 | 100                 | Y                    | 1275          | 1219    | 1335    |                                       |
| 113      | 3                   | 100                 | Y                    | 1124          | 1124    | 1124    | a,g                                   |
| 103a     | 100                 | 100                 | Y                    | 1141          | 1102    | 1174    |                                       |
| 105      | 100                 | 100                 | Y                    | 1071          | 1044    | 1100    |                                       |
| 110      | 100                 | 96                  | Y                    | 1237          | 1100    | 1367    |                                       |
| 116a     | 100                 | 100                 | Y                    | 1065          | 1039    | 1104    |                                       |
| 123      | 100                 | 44                  | Y                    | 826           | 773     | 850     |                                       |
| 125      | 100                 | 93                  | Y                    | 757           | 719     | 781     |                                       |
| 124      | 0                   | -                   | -                    | -             | -       | -       | h                                     |
| 138      | 65                  | 100                 | Y                    | 1074          | 1032    | 1109    | b                                     |
| 118      | 61                  | 100                 | Y                    | 1005          | 961     | 1036    | b                                     |
| 134      | 89                  | 96                  | Y                    | 724           | 456     | 917     | b, d                                  |
| 120a     | 1                   | 100                 | Y                    | 1142          | 881     | 1415    | a, g                                  |
| 122      | 100                 | 100                 | Y                    | 569           | 373     | 795     |                                       |
| 102      | 3                   | 100                 | Y                    | 1342          | 1212    | 1395    | a                                     |
| 104      | 100                 | 100                 | Y                    | 1208          | 1160    | 1265    |                                       |
| 106a     | 23                  | 100                 | Y                    | 1202          | 1163    | 1379    | a                                     |
| 135a     | 13                  | 100                 | Y                    | 1173          | 1155    | 1232    | a                                     |
| 111      | 70                  | 17                  | Y                    | 1318          | 1200    | 1407    | a                                     |
| 126a     | 1.5                 | 100                 | Y                    | 1240          | 1206    | 1379    | a                                     |
| 116b     | 100                 | 100                 | Y                    | 1155          | 1130    | 1179    |                                       |
| 165      | 56                  | 100                 | Y                    | 1112          | 1016    | 1204    | b                                     |
| 103b     | 76                  | 99                  | Y                    | 1133          | 1094    | 1175    | b                                     |
| 170      | 80                  | 00                  | N                    | 1131          | 1131    | 1131    | c, f                                  |
| 107      | 100                 | 94                  | Y                    | 806           | 624     | 924     |                                       |
| 109      | 100                 | 100                 | Y                    | 724           | 496     | 908     |                                       |
| 114      | 52                  | 100                 | Y                    | 814           | 497     | 874     | b                                     |
| 121a     | 1                   | 100                 | Y                    | 1360          | 1319    | 1391    | a                                     |
| 100      | 100                 | 100                 | Y                    | 1091          | 1038    | 1142    | 50-day on baseline gap                |
| 108      | 45                  | 100                 | Y                    | 1100          | 1031    | 1147    | b                                     |
| 128      | 74                  | 100                 | Y                    | 1118          | 1079    | 1153    | b                                     |
| 132      | 40                  | 100                 | Y                    | 1112          | 1052    | 1158    | b, e                                  |
| 119      | 100                 | 100                 | Y                    | 1105          | 1017    | 1166    |                                       |
| 166      | 73                  | 99                  | N                    | 1185          | 1160    | 1223    | 1 <sup>st</sup> 27 recs pre-launch, b |
| 117      | 100                 | 42                  | Y                    | 1094          | 1054    | 1148    |                                       |
| 127      | 44                  | 100                 | Y                    | 1179          | 1077    | 1230    | b                                     |

Table 3. Float Performance (continued)

| Float ID | % Mission Completed | % Messages Received | Temp Corrected (Y/N) | Pressure (db) |         |         | Comments |
|----------|---------------------|---------------------|----------------------|---------------|---------|---------|----------|
|          |                     |                     |                      | Mean          | Minimum | Maximum |          |
| 112      | 100                 | 100                 | Y                    | 1152          | 1084    | 1223    |          |
| 126b     | 60                  | 99                  | Y                    | 1176          | 1140    | 1212    | b        |
| 130      | 91                  | 99                  | Y                    | 1070          | 1011    | 1148    | b        |
| 135b     | 34                  | 100                 | Y                    | 1202          | 1142    | 1240    | b        |
| 167      | 74                  | 49                  | N                    | 1066          | 992     | 1173    | b        |
| 164      | 68                  | 100                 | N                    | 1144          | 1103    | 1188    | b        |
| 169      | 75                  | 100                 | N                    | 1119          | 1075    | 1171    | b        |
| 115      | 61                  | 100                 | Y                    | 1088          | 1004    | 1159    | b        |
| 129      | 62                  | 87                  | Y                    | 1170          | 1139    | 1201    | b        |
| 139      | 57                  | 100                 | Y                    | 1126          | 1101    | 1160    | b        |
| 120b     | 100                 | 99                  | Y                    | 1085          | 1025    | 1136    |          |
| 121b     | 89                  | 100                 | Y                    | 1129          | 981     | 1181    | b        |
| 106b     | 100                 | 100                 | Y                    | 1164          | 1141    | 1196    |          |

## Key to Comments:

a – surfaced early due to overpressure

b – surfaced early due to lost ballast weight

c – surfaced early due to low battery voltage

d – sampled every 16 hours

e – no acoustics

f – float reset at surface; no useful data

g – float surfaced immediately after launch; no useful data

h – never heard

For floats with the data stored in compressed format, pressure and temperature are stored in the last three bytes of the message (the middle byte is split between them). WHOI takes care of the 1000 counts that have been subtracted from the pressure by the float in the calibration step. The pressure counts are divided by 1000, then linear coefficients are applied, and the result is divided by 10. If the result is more than 500 db from the target pressure, a rollover is assumed, 4096 is added to the raw counts and pressure recomputed. Raw counts are output as well as the result.

$$P = (pc1 + pc2 \times praw) \div 10$$

$$\text{where } praw = pcounts[+4096] \div 1000$$

Temperature raw counts initially have 1000 added to them, for output as well as subsequent processing. Then logarithmic coefficients are applied. The result is divided into 1000, then 273.16 is subtracted. If the result is more than 5 degrees from the target temperature, a rollover is assumed, 4096 is added to the raw counts and the temperature is recomputed.

$$T = [1000 \div (tc1 + tc2 \times traw^2 + tc3 \times traw^3)] - 273.16$$

$$\text{where } traw = \log((tcounts + 1000[+4096]) \div 1000)$$

Table 4. Float Clock Net Offsets and Temperature and Pressure Coefficients

| Float No. | Net Offset (seconds) | Temperature Coefficients (logarithmic) |        |        | Pressure Coefficients (linear) |        |
|-----------|----------------------|--|--------|--------|--------------------------------|--------|
| 100       | -35.98               | 3.1504                                 | 0.2683 | 0.0072 | 94.0                           | 2783.0 |
| 101       | 0.12                 | 3.1510                                 | 0.2669 | 0.0074 | 0.0                            | 2774.0 |
| 102       | 0.00                 | 3.1502                                 | 0.2717 | 0.0069 | 74.0                           | 2783.0 |
| 103a      | 0.00                 | 3.1483                                 | 0.2675 | 0.0074 | 9.0                            | 2730.0 |
| 103b      | 0.00                 | 3.1483                                 | 0.2675 | 0.0074 | 9.0                            | 2730.0 |
| 104       | -6.88                | 3.1498                                 | 0.2690 | 0.0072 | -23.0                          | 2789.0 |
| 105       | 0.00                 | 3.1473                                 | 0.2707 | 0.0069 | 81.0                           | 2757.0 |
| 106a      | 0.00                 | 3.1460                                 | 0.2695 | 0.0067 | 102.0                          | 2741.0 |
| 106b      | 1.19                 | 3.1460                                 | 0.2695 | 0.0067 | -20.0                          | 2750.0 |
| 107       | -3.88                | 3.1502                                 | 0.2686 | 0.0071 | 93.0                           | 2774.0 |
| 108       | -0.58                | 3.1535                                 | 0.2651 | 0.0079 | 84.0                           | 2784.0 |
| 109       | -0.38                | 3.1504                                 | 0.2685 | 0.0071 | 46.0                           | 2763.0 |
| 110       | -10.60               | 3.1507                                 | 0.2700 | 0.0070 | 19.0                           | 2771.0 |
| 111       | -6.50                | 3.1507                                 | 0.2688 | 0.0071 | 212.0                          | 2781.0 |
| 112       | -13.80               | 3.1497                                 | 0.2682 | 0.0071 | 273.0                          | 2764.0 |
| 114       | -1.34                | 3.1513                                 | 0.2674 | 0.0073 | 105.0                          | 2782.0 |
| 115       | -22.84               | 3.1505                                 | 0.2686 | 0.0071 | 111.0                          | 2773.0 |
| 116a      | 0.60                 | 3.1509                                 | 0.2686 | 0.0072 | 193.0                          | 2757.0 |
| 116b      | 3.69                 | 3.1509                                 | 0.2686 | 0.0072 | 193.0                          | 2757.0 |
| 117       | -5.81                | 3.1510                                 | 0.2698 | 0.0070 | 55.0                           | 2745.0 |
| 118       | 9.40                 | 3.1508                                 | 0.2676 | 0.0074 | 7.0                            | 2745.0 |
| 119       | 1.00                 | 3.1515                                 | 0.2673 | 0.0073 | 110.0                          | 2785.0 |
| 120b      | -19.31               | 3.1502                                 | 0.2690 | 0.0070 | 73.0                           | 2796.0 |
| 121b      | -12.71               | 3.1516                                 | 0.2647 | 0.0076 | -18.0                          | 2784.0 |
| 122       | 15.12                | 3.1507                                 | 0.2682 | 0.0071 | 34.0                           | 2782.0 |
| 123       | 0.12                 | 3.1341                                 | 0.2859 | 0.0044 | -49.0                          | 2754.0 |
| 125       | 1.10                 | 3.1499                                 | 0.2678 | 0.0071 | 114.0                          | 2792.0 |
| 126a      | 0.00                 | 3.1507                                 | 0.2688 | 0.0071 | 212.0                          | 2781.0 |
| 126b      | -11.58               | 3.1507                                 | 0.2713 | 0.0067 | -3.0                           | 2785.0 |
| 127       | 10.30                | 3.1484                                 | 0.2690 | 0.0069 | 253.0                          | 2726.0 |
| 128       | -5.46                | 3.1544                                 | 0.2671 | 0.0074 | 118.0                          | 2757.0 |
| 129       | -2.46                | 3.1485                                 | 0.2685 | 0.0070 | 31.0                           | 2792.0 |
| 130       | 1.54                 | 3.1480                                 | 0.2716 | 0.0064 | 154.0                          | 2762.0 |
| 132       | 0.00                 | 3.1516                                 | 0.2681 | 0.0073 | 60.0                           | 2775.0 |
| 134       | 7.66                 | 3.1479                                 | 0.2704 | 0.0070 | 12.0                           | 2778.0 |
| 135a      | 0.00                 | 3.1527                                 | 0.2648 | 0.0078 | 196.0                          | 2778.0 |
| 135b      | -1.00                | 3.1527                                 | 0.2648 | 0.0078 | 72.0                           | 2787.0 |
| 138       | 8.40                 | 3.1492                                 | 0.2695 | 0.0071 | -5.0                           | 2866.0 |
| 139       | -20.30               | 3.1506                                 | 0.2679 | 0.0074 | 84.0                           | 2776.0 |
| 164       | -15.46               | 3.1312                                 | 0.2885 | 0.0039 | 4.0                            | 2790.0 |
| 165       | 4.54                 | 3.1144                                 | 0.3079 | 0.0400 | 76.0                           | 2775.0 |
| 166       | -10.48               | 3.1271                                 | 0.2903 | 0.0032 | 205.0                          | 2761.0 |
| 167       | -0.46                | 3.1314                                 | 0.2847 | 0.0046 | 194.0                          | 2773.0 |
| 169       | -14.58               | 3.1465                                 | 0.2702 | 0.0074 | 228.0                          | 2767.0 |

Table 5. Sound Sources Used

| Float No. | M1 | M2 | M3 | N | A2 | C | G |
|-----------|----|----|----|---|----|---|---|
| 100       | X  | X  | X  | X |    |   |   |
| 101       | X  | X  | X  |   |    |   |   |
| 102       | X  | X  |    |   |    |   |   |
| 103a      | X  | X  | X  |   |    |   |   |
| 103b      | X  | X  | X  | X |    |   |   |
| 104       | X  | X  | X  | X | X  |   |   |
| 105       | X  | X  | X  | X | X  |   |   |
| 106a      | X  | X  |    |   |    |   |   |
| 106b      | X  | X  | X  |   |    |   |   |
| 107       | X  | X  | X  | X |    |   |   |
| 108       | X  | X  | X  | X | X  |   |   |
| 109       | X  | X  | X  | X |    |   |   |
| * 110     | X  | X  | X  | X | X  | X | X |
| 111       | X  | X  |    |   |    |   |   |
| 112       | X  | X  | X  | X |    |   |   |
| 114       | X  | X  | X  | X | X  | X |   |
| 115       | X  | X  | X  |   |    |   |   |
| 116a      | X  | X  | X  | X | X  |   |   |
| 116b      | X  | X  | X  |   |    |   |   |
| 117       | X  | X  | X  | X | X  |   |   |
| 118       | X  | X  | X  | X |    |   |   |
| 119       | X  | X  | X  | X |    |   |   |
| 120a      | X  | X  |    |   |    |   |   |
| 120b      | X  | X  | X  | X |    |   |   |
| 121a      | X  | X  |    |   |    |   |   |
| 121b      | X  | X  | X  |   |    |   |   |
| 122       | X  | X  | X  | X | X  | X | X |
| 123       | X  | X  | X  |   |    |   |   |
| 125       | X  | X  | X  |   |    |   |   |
| 126a      | X  | X  |    |   |    |   |   |
| 126b      | X  | X  | X  | X |    |   |   |
| 127       | X  | X  | X  | X |    |   |   |
| 128       | X  | X  | X  | X | X  |   |   |
| 129       | X  | X  | X  | X | X  |   |   |
| 130       | X  | X  | X  |   |    |   |   |
| ** 134    | X  | X  | X  | X | X  |   |   |
| 135a      | X  | X  |    |   |    |   |   |
| 135b      | X  | X  | X  | X | X  |   |   |
| 138       | X  | X  | X  | X | X  |   |   |
| 139       | X  | X  | X  | X |    |   |   |
| 164       | X  | X  | X  |   |    |   |   |
| 165       | X  | X  | X  |   |    |   |   |
| 166       | X  | X  | X  |   |    |   |   |
| 167       | X  | X  | X  | X |    |   |   |
| 169       | X  | X  | X  | X |    |   |   |

\* 110 may have used G until 940116

\*\* 134 may have used G until 931223

The .dat file is produced according to the above steps. On re-examination of the calibration methods, it was found that a systematic offset had been introduced into the temperatures for the earliest floats calibrated. A value of 0.375°C was added to all temperatures except for floats 164 through 169 (see Table 3). Temperature and pressure coefficients for each float are listed in Table 4.

Plots of temperature, pressure, and TOAs in each half-hour window were made at this point. Temperatures and pressures were only edited if they were clearly outside the range of values, and were replaced using linear interpolation. The sources to be extracted were selected and the TOAs and their correlation heights for each source-float pair were transferred into a file. (See Table 5 for a list of sound sources used to track each float.) The clock-drift of the float may be applied at this time, or later. The TOAs were usually edited at this point. The next step was to linearly interpolate missing TOAs (limited to one-day gaps for some meddy floats, and three days for others), apply Doppler correction and source clock-drifts, if known, and interpolate first and third listening windows to the time of the second.

Standard processing had formerly used the five previous values of TOAs to predict a Doppler correction. This gave a poor result on curving trajectories. A new algorithm was instituted which used the previous and next TOAs to compute the correction (with extrapolation at the end of the segments).

A sound velocity of 1.501 km/s was chosen to convert TOAs to distance based on ray-tracing information supplied by Michel Ollitrault at IFREMER (personal communication). Locations were calculated using two or more sources and a routine that uses a least-squares fit. Bad track locations were detected based on plots and speed and direction information. If the error was too large, TOAs were omitted based on correlation height, and the position recalculated. Some sources were routinely avoided after clock problems were detected (M3 and G). Some floats near the end of the experiment had intervals where no computation could be made because the float was on the base line of the only source pair available. Cubic spline interpolation was used to fill in short gaps in latitude and longitude (under five days for most floats, one day for floats in some meddies). Where the cubic spline interpolation gave physically unrealistic results, those segments were cut out of the final track.

One exceptional case was float 134 for which the listening interval proved to be 16 hours, instead of the eight hours expected. This was diagnosed because it had exactly half the number of messages expected, and by comparing the timing of the sudden change in M3's clock to other floats.

## 7. Acknowledgements

We are grateful to the captain, Frank Robben, and the crew of Kialoa II for their support, skill and patience in this ambitious field program. We also especially acknowledge the efforts of Rita Klabacha from Laurence Armi's lab at the Scripps

Institution of Oceanography, who expertly managed details of the seagoing program from Vilamoura and on each of the trips on board Kialoa II. We thank the students and staff from the Oceanography Group of the University of Lisbon, particularly Fatima Sousa, without whose help this project would not have been possible. The efforts of Jim Valdes, Brian Guest and Bob Tavares of the WHOI Float Operations Group helped make this program a success. This work has been sponsored by the National Science Foundation through Grant No. OCE-91-01033 to the Woods Hole Oceanographic Institution and Grant No. OCE-91-00724 to Scripps Institution of Oceanography, and by the Luso-American Foundation for the Development - FLAD - through Grant No. 54/93 to the University of Lisbon. We gratefully thank the Government of Portugal for their support of this project.

## 8. References

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- Rossby, T., D. Dorson, and J. Fontaine, 1986. The RAFOS system. *J. Atmos. Oceanic Technol.*, **3**, 672-679.

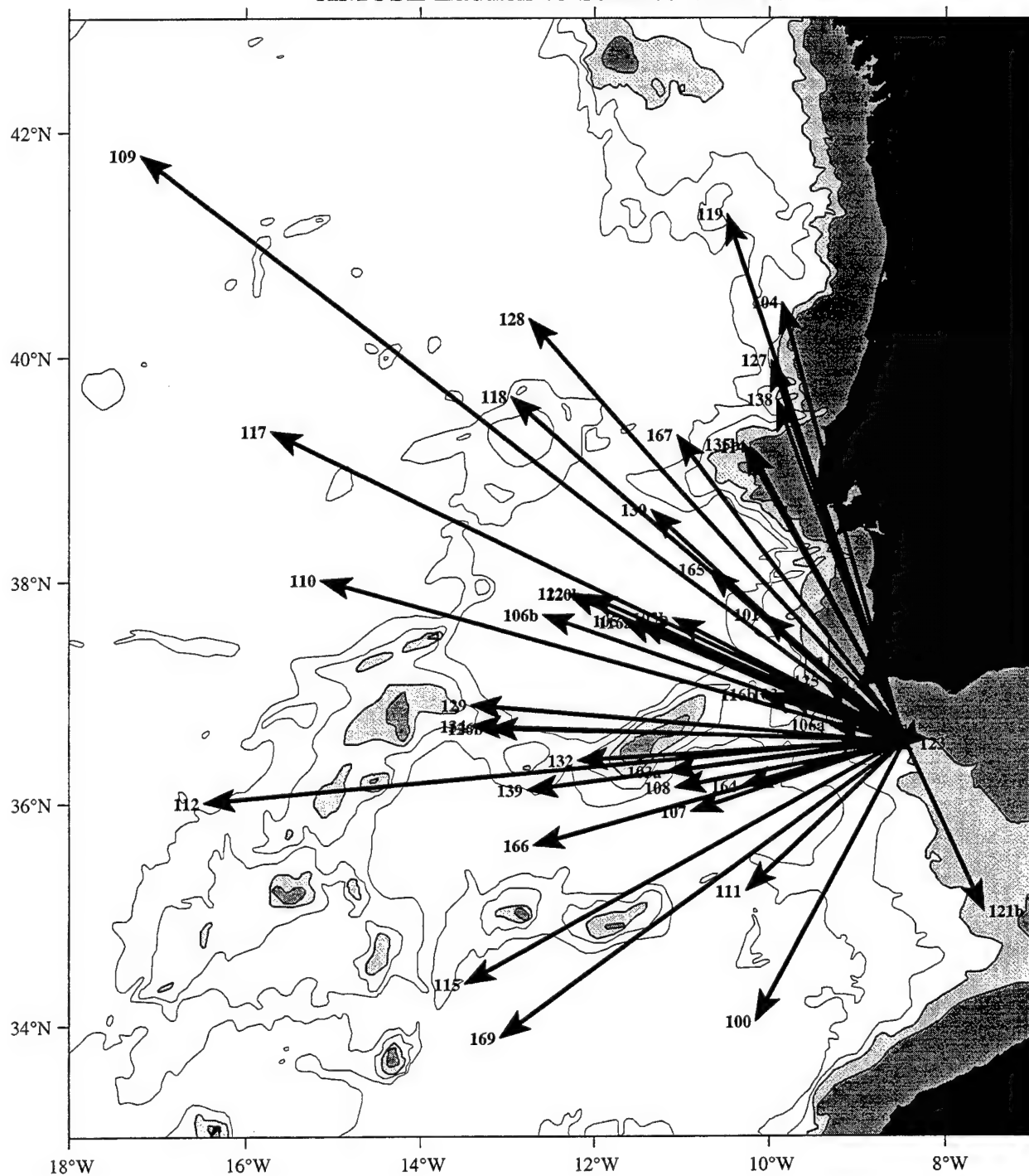


## **Appendix A:**

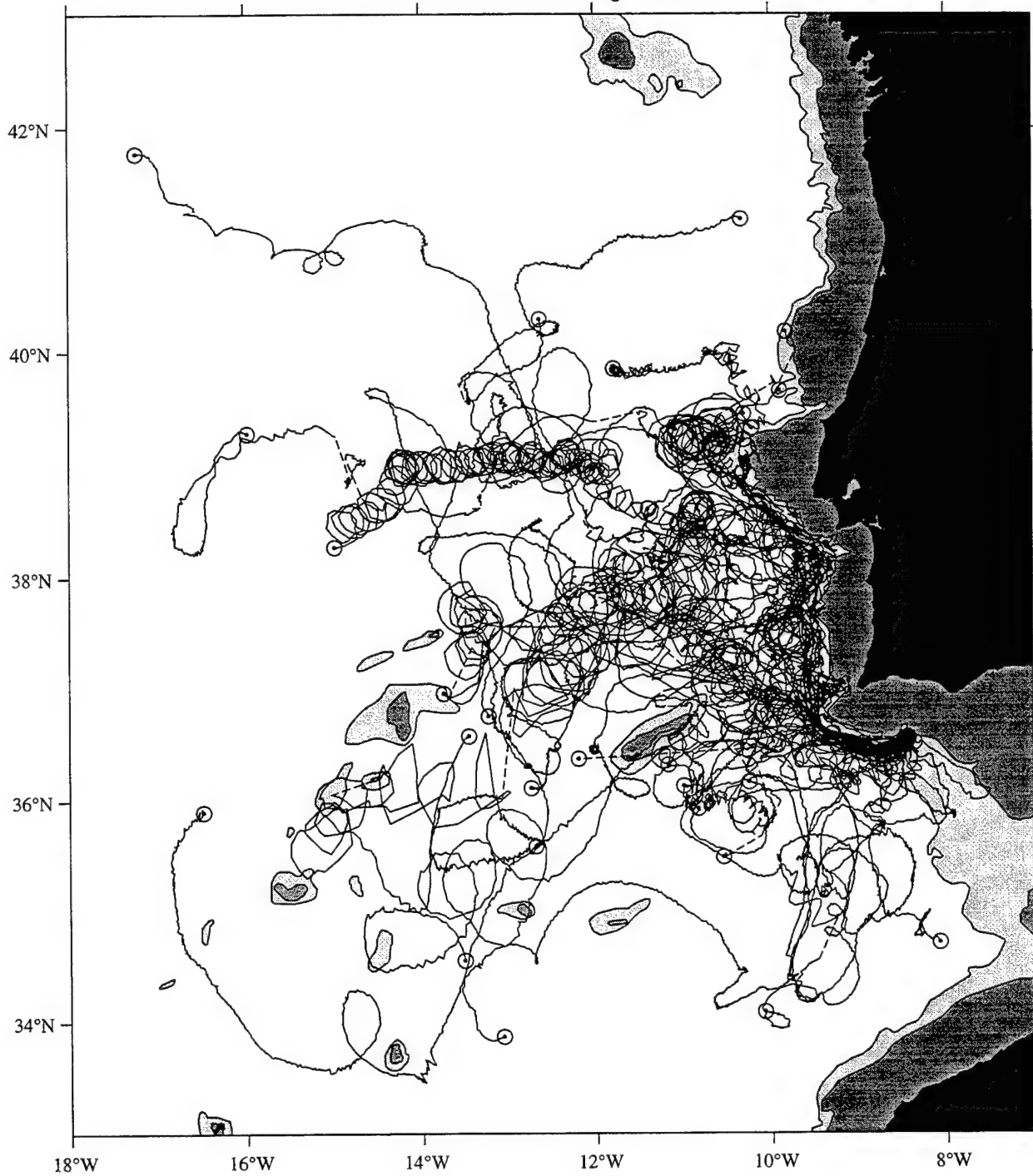
### **Vector and spaghetti plots, float track gallery.**

Here we present launch-to-surface vector diagrams and 'spaghetti' diagrams for all the floats and for float track segments in meddies. A float track 'gallery' provides an overview of all float tracks on the same scale, shown in order of deployment. In the launch-to-surface vector diagrams, launch positions are marked as dots; surface positions are marked as arrowheads. Float labels are at the surface points. The spaghetti diagrams show an 'into the page' (circle-x) symbol as the launch position, and an 'out of the page' (circle-dot) symbol as the surface position. Float tracks are the solid black lines, and untrackable segments are represented as dashed lines. The symbols of the track gallery follow that of the spaghetti diagrams. A gallery track title lists cruise name, date (yymmdd), and float ID. There were usually two floats deployed per cruise, where there were three floats deployed on a single cruise; three tracks are grouped on a single page. The 1000 and 2000 meter isobaths are shown in shades of gray on all plots. In addition, the launch-to-surface vector plots have contours (unshaded) for the 3000 and 4000 meter isobaths.

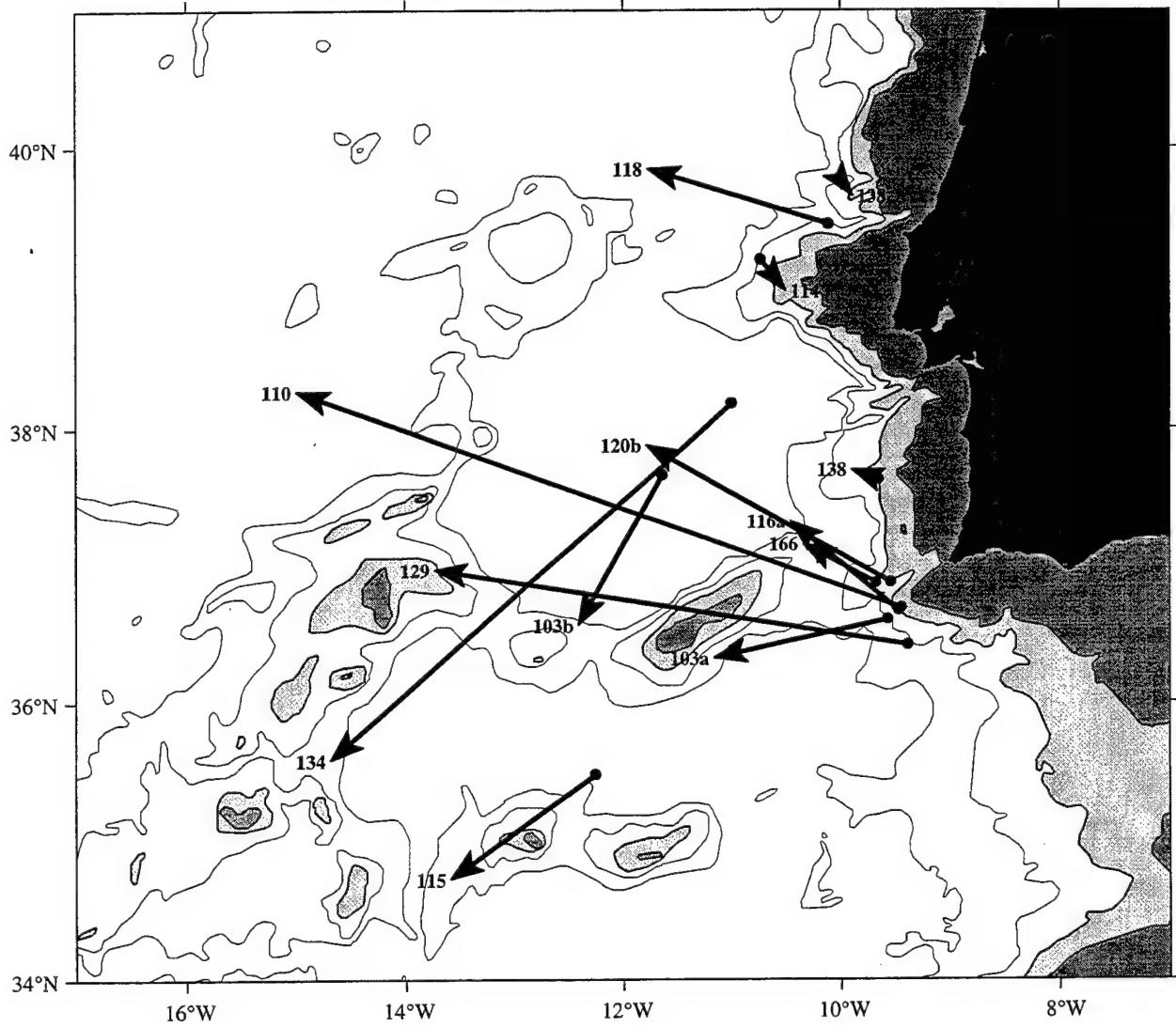
# AMUSE Launch-to-Surface Vectors



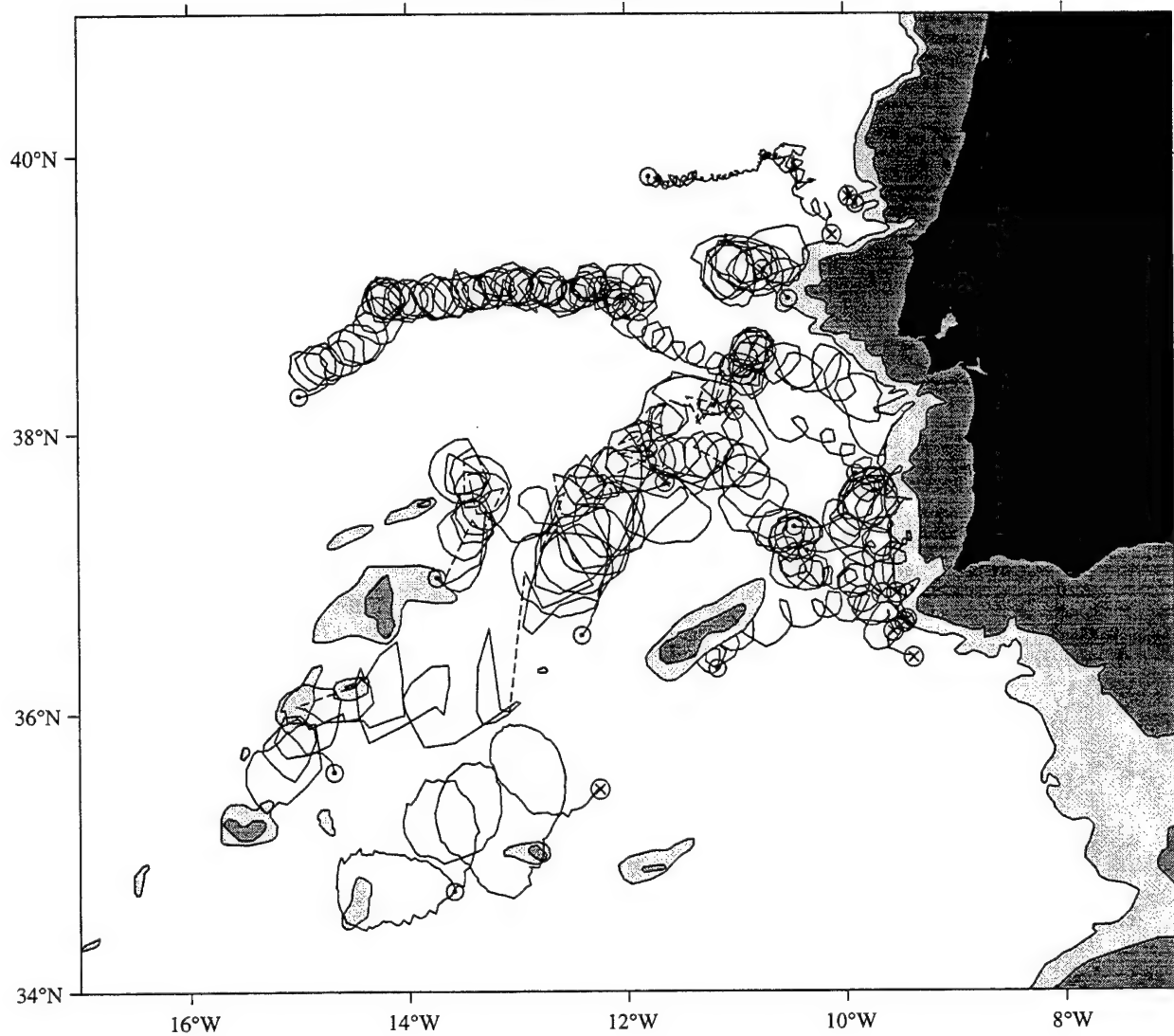
# AMUSE Float Trajectories



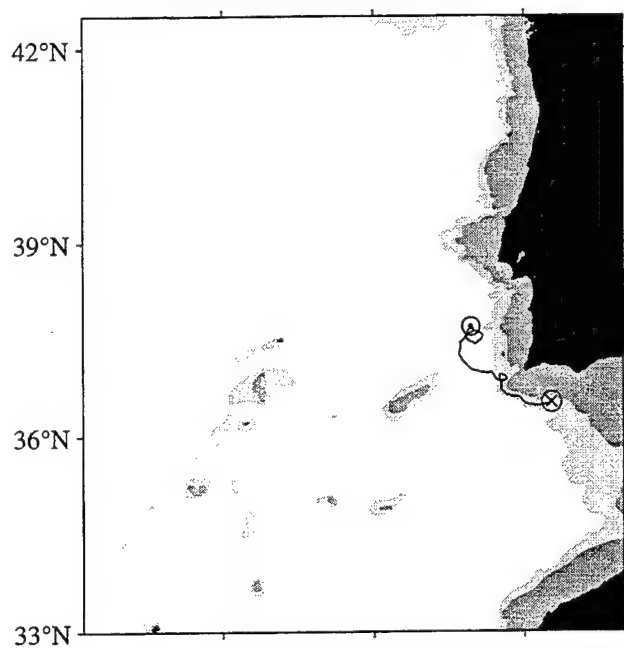
### AMUSE Meddy Launch-to-Surface Vectors



### AMUSE Meddy Float Trajectories



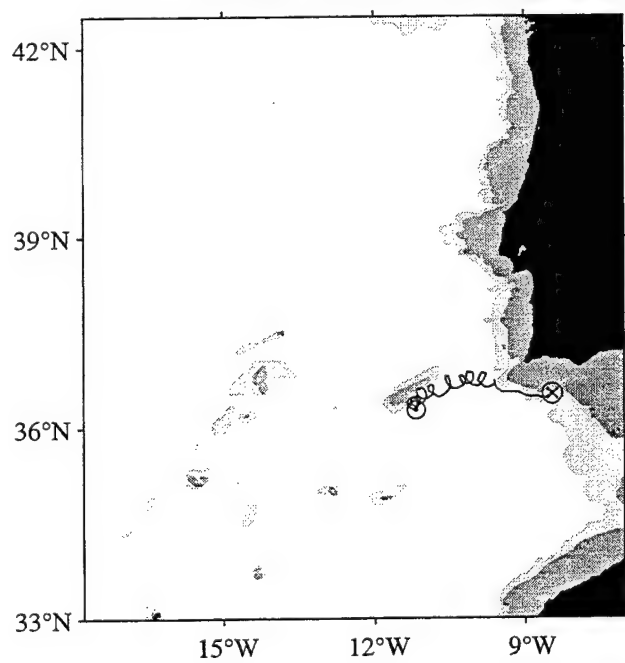
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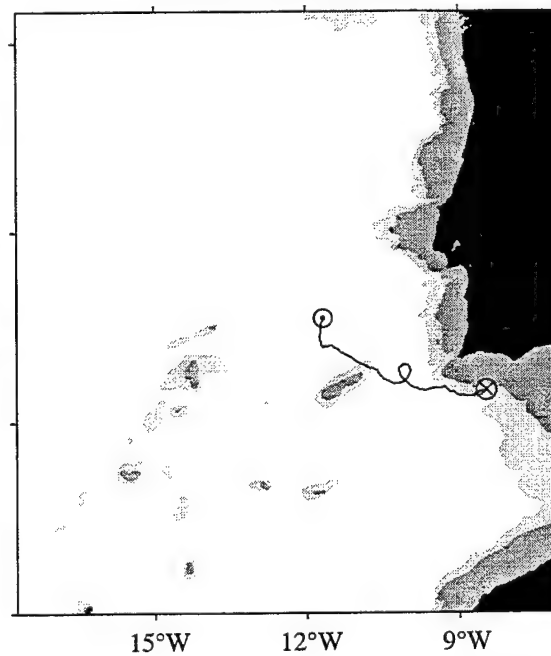
**OCctd111: 930511: am113**



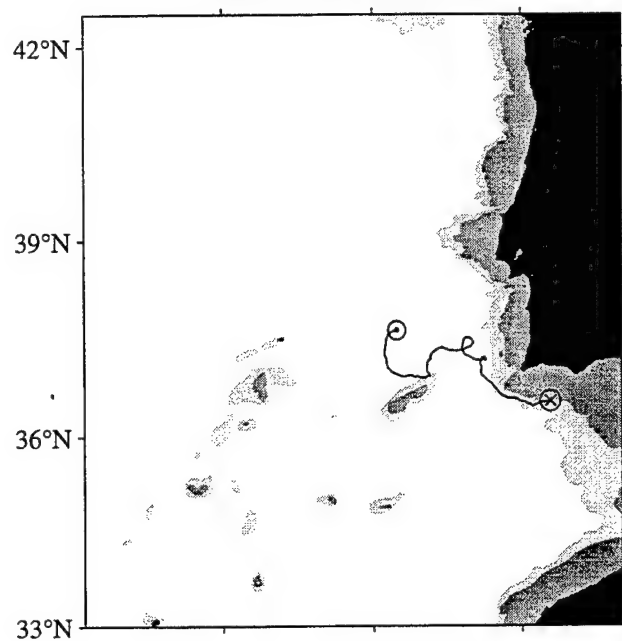
**K0106: 930705: am103a**



**K0107: 930705: am105**



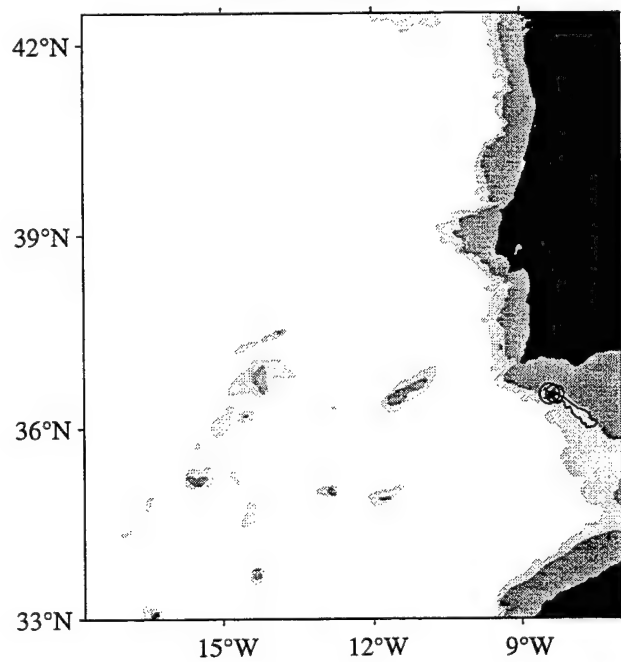
**K0205: 930715: am116a**



**K0207A: 930715: am110**



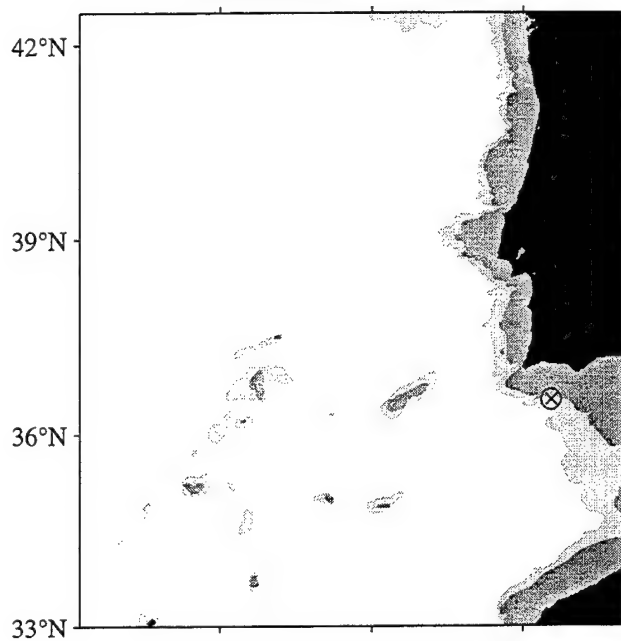
**K0306: 930821: am123**



**K0307: 930821: am125**



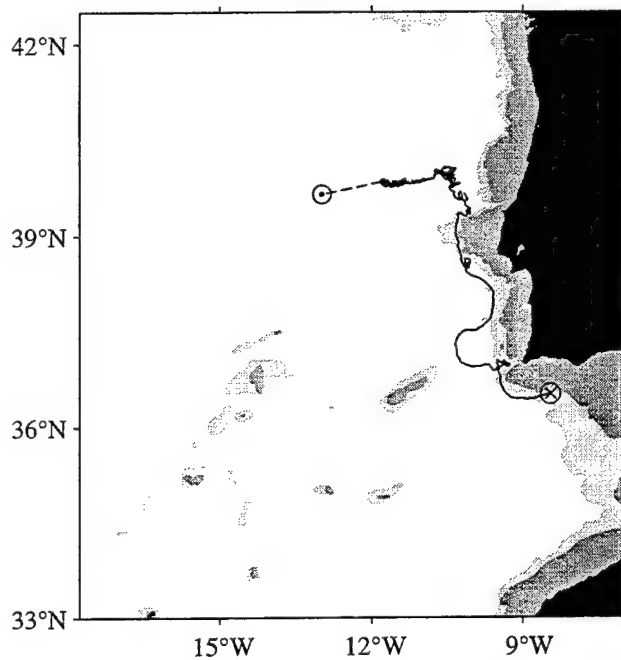
**K0405A: 930828: am124**



**K0407: 930828: am138**



**K0506: 930904: am118**

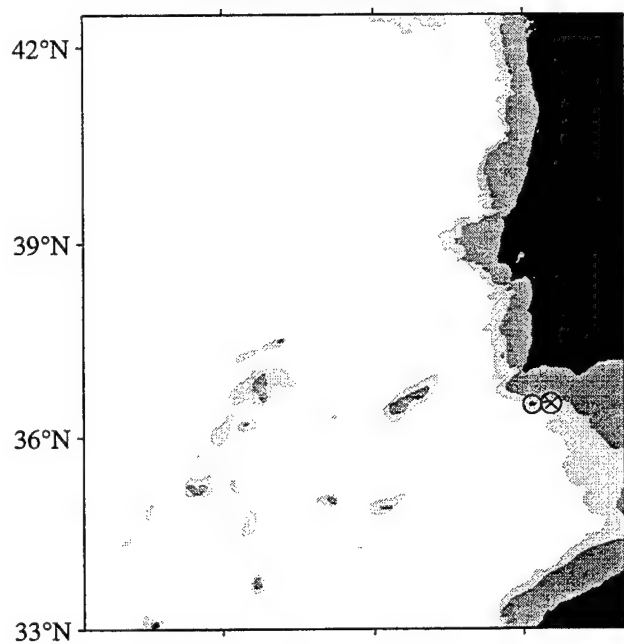


**K0507: 930904: am134**





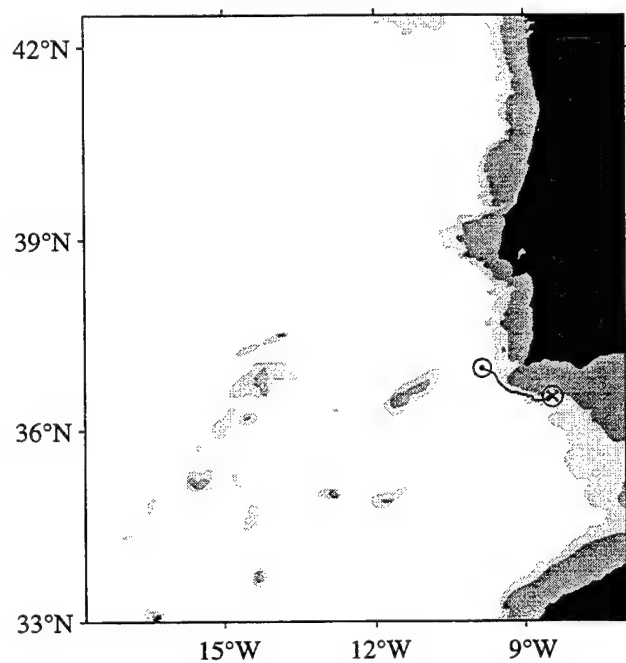
**K0606A: 930911: am120a**



**K0607A: 930911: am122**



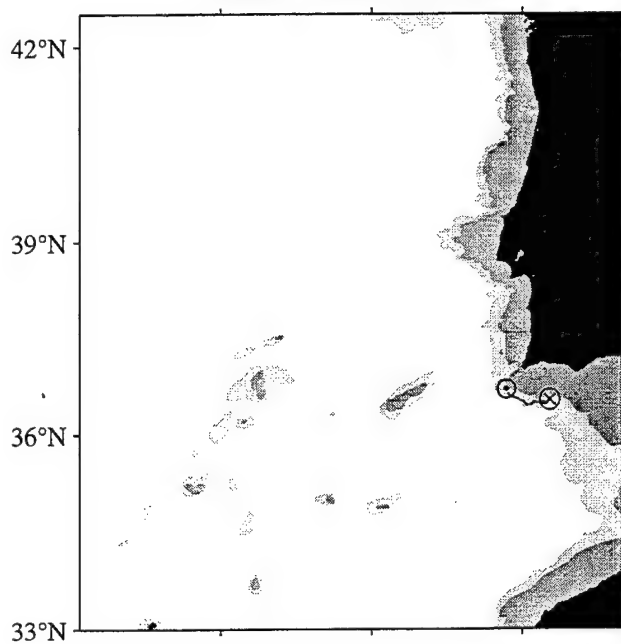
**K0706: 930918: am102**



**K0707A: 930918: am104**



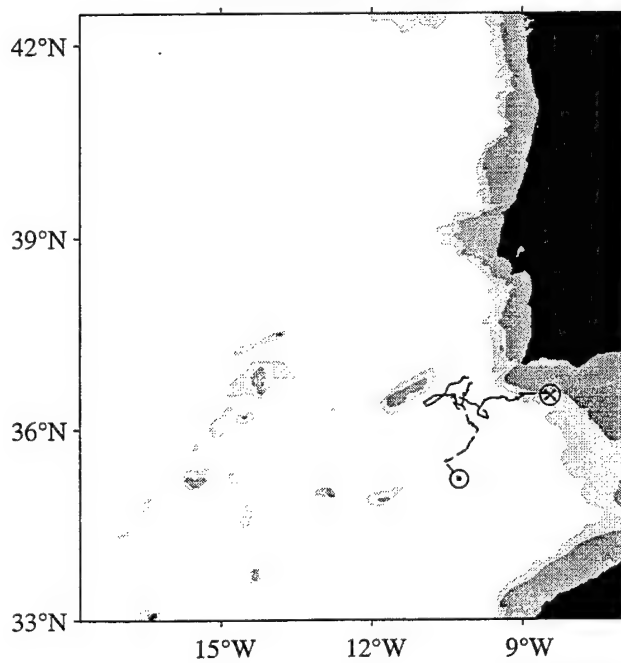
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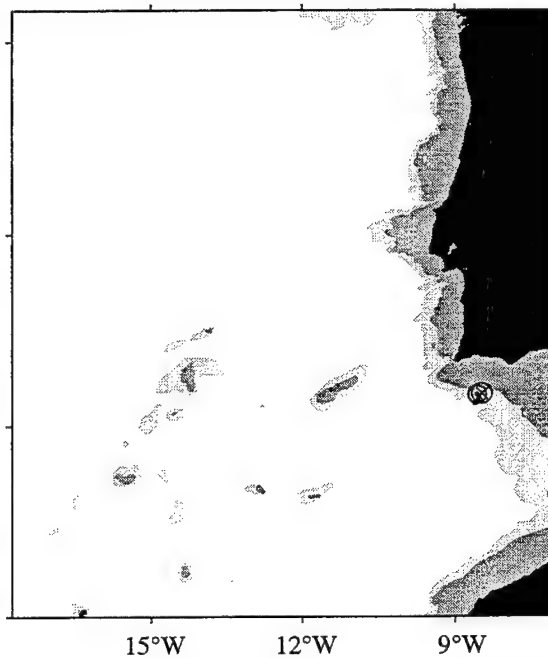
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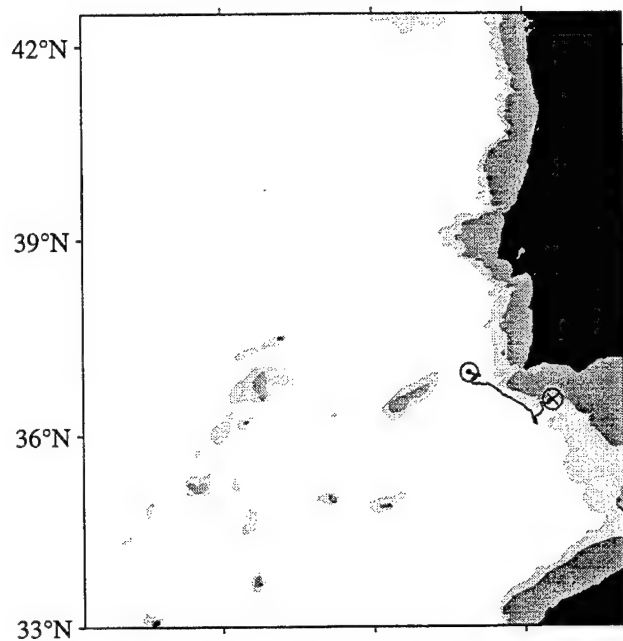
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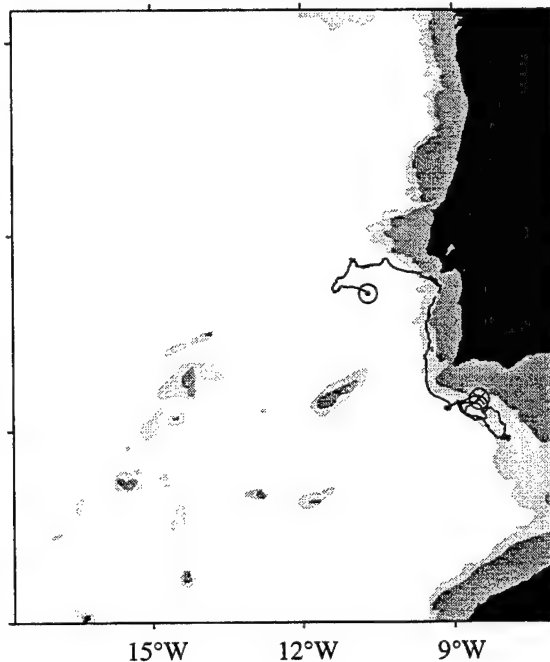
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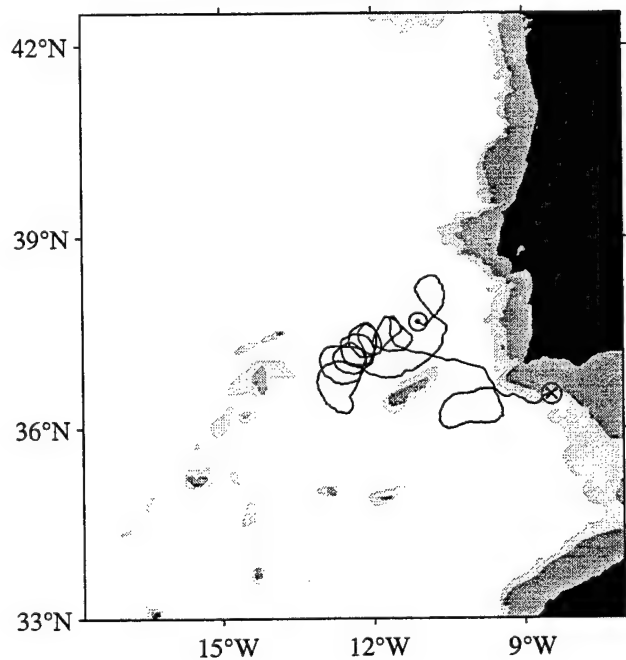
**K1205A: 931204: am116b**



**K1208: 931204: am165**



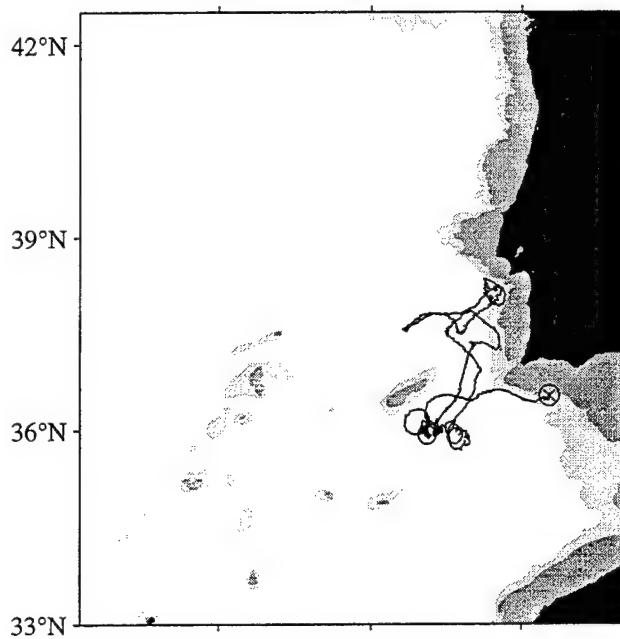
**K1306: 931211: am103b**



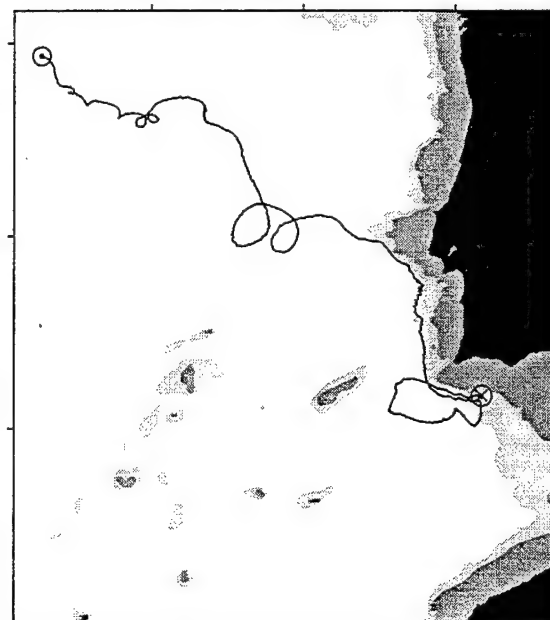
**K1307A: 931211: am170**



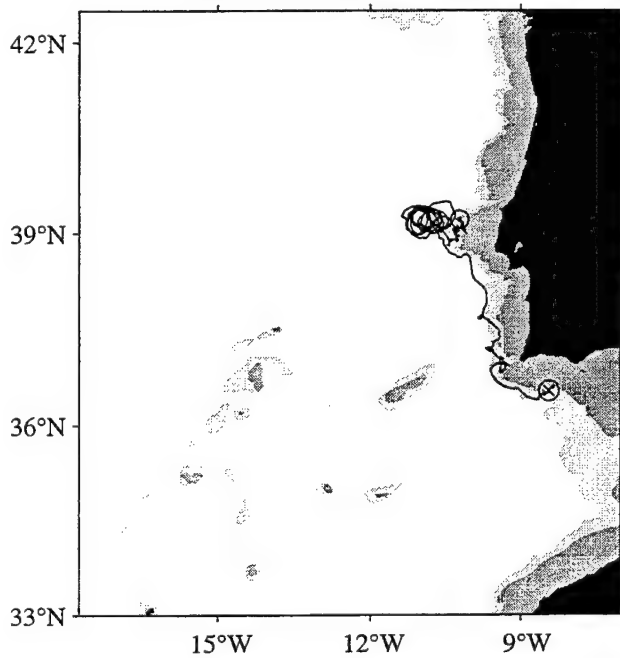
**K1406: 931220: am107**



**K1407A: 931220: am109**



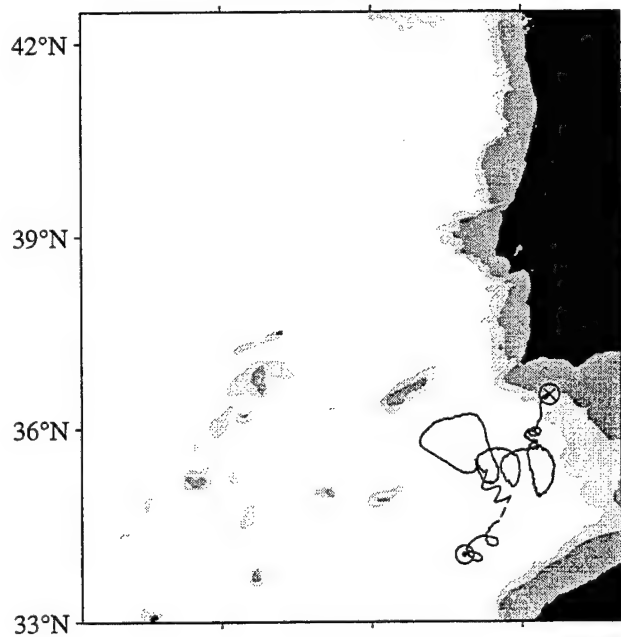
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**K1506A: 940104: am121a**



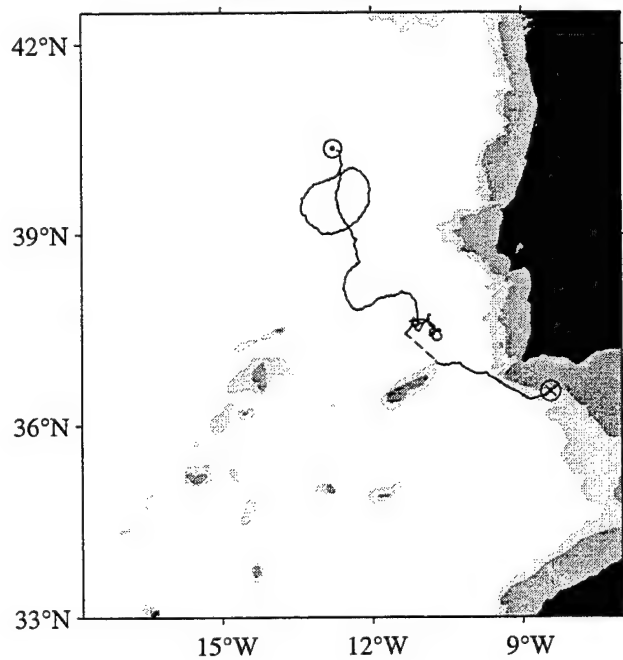
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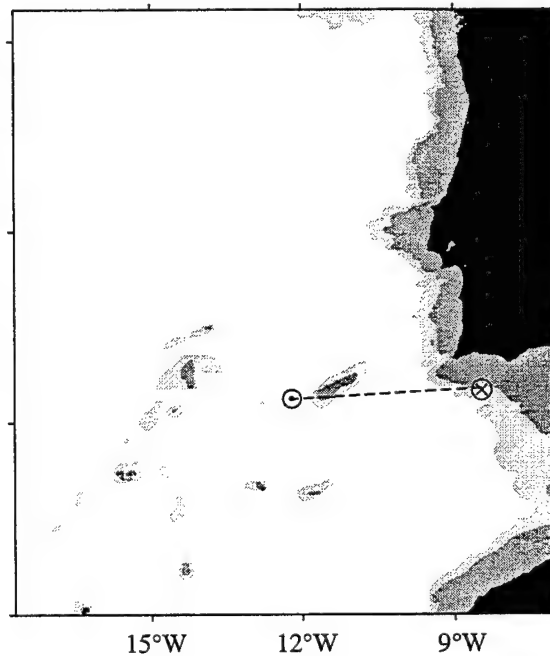
**K1608: 940108: am108**



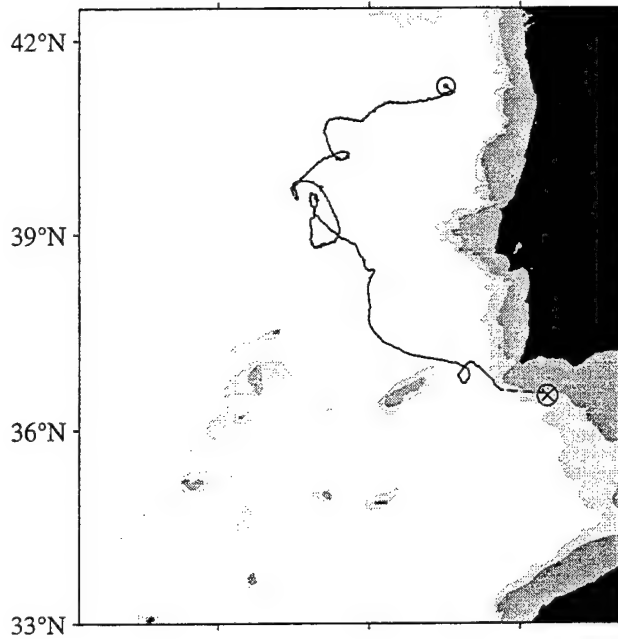
**K1705A: 940115: am128**



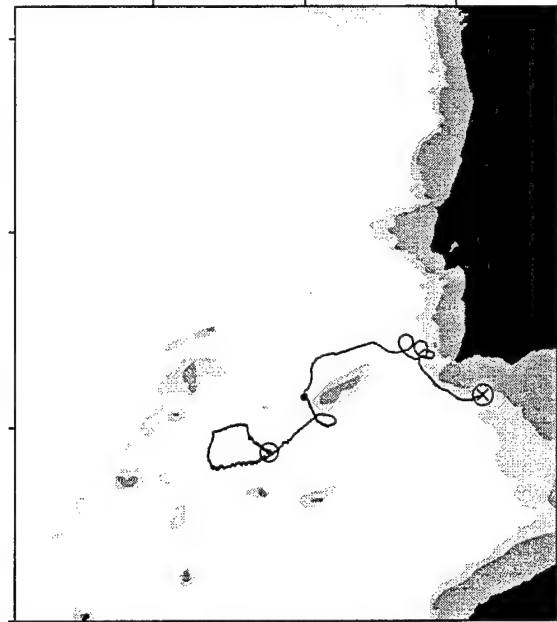
**K1706A: 940115: am132**



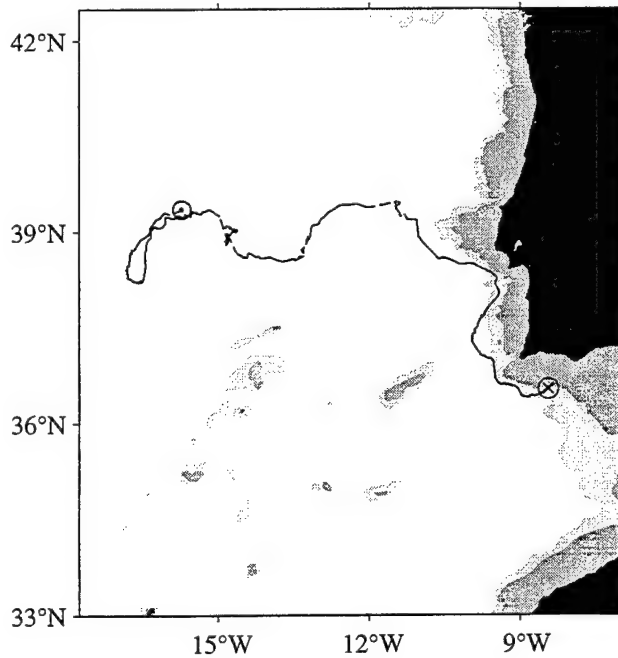
**K1806A: 940122: am119**



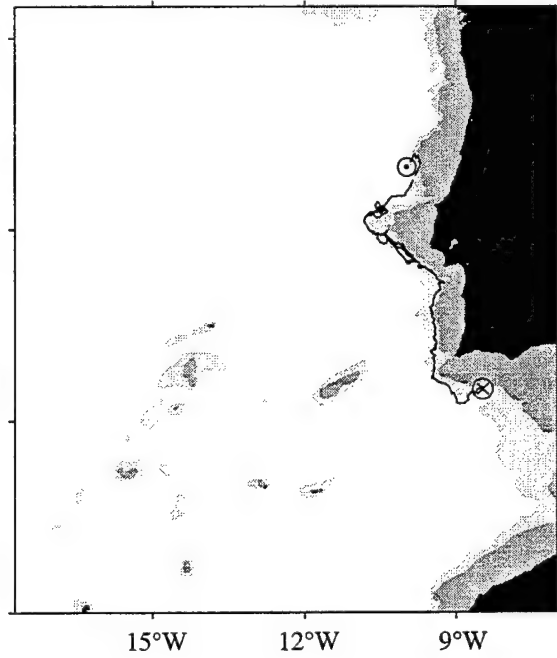
**K1807A: 940122: am166**



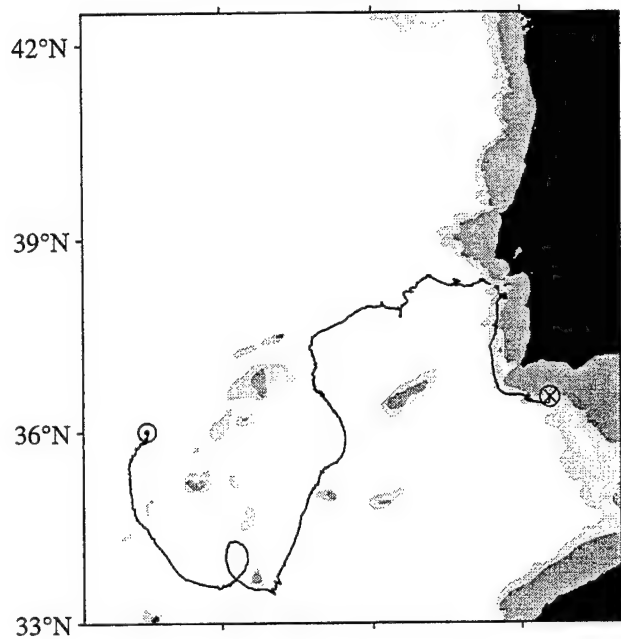
**K1905A: 940129: am117**



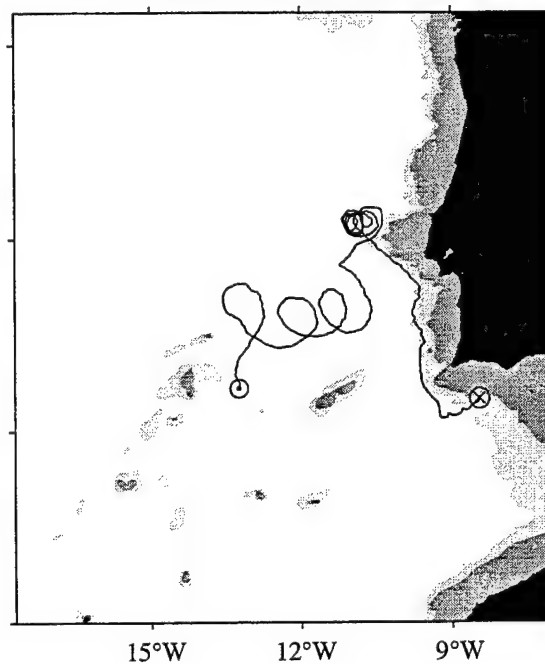
**K1907A: 940129: am127**



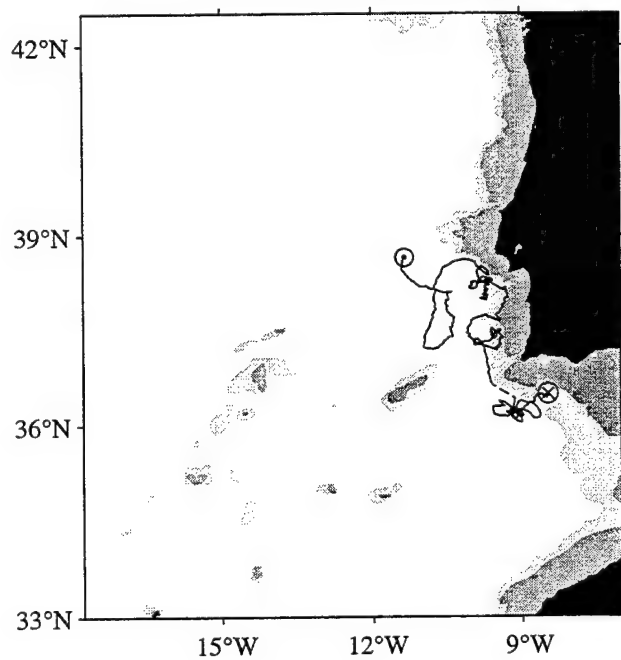
**K2005A: 940205: am112**



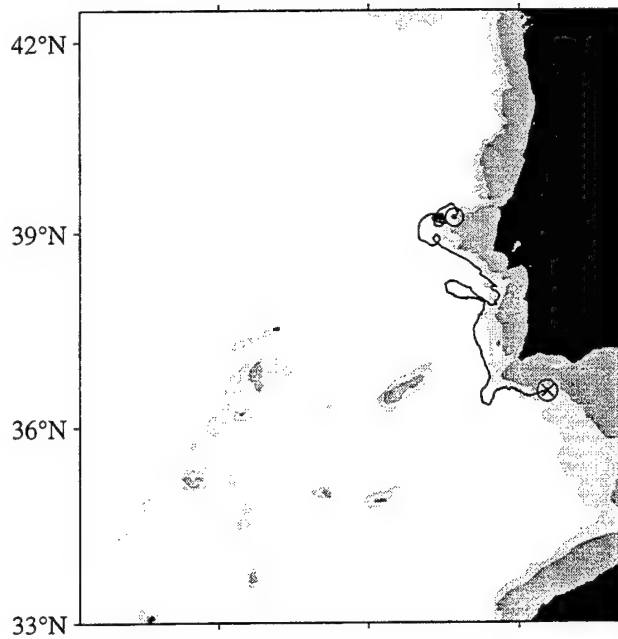
**K2006A: 940205: am126b**



**K2007A: 940205: am130**



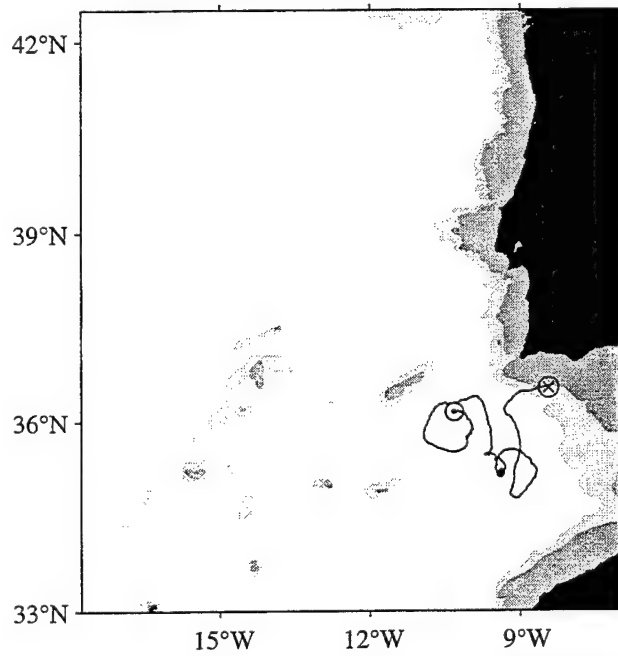
**K2105A: 940213: am135b**



**K2106A: 940213: am167**



**K2205A: 940219: am164**

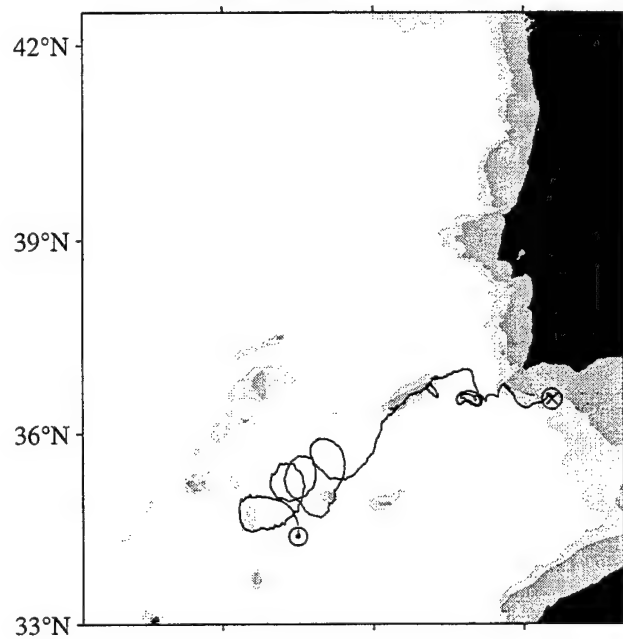


**K2207: 940219: am169**

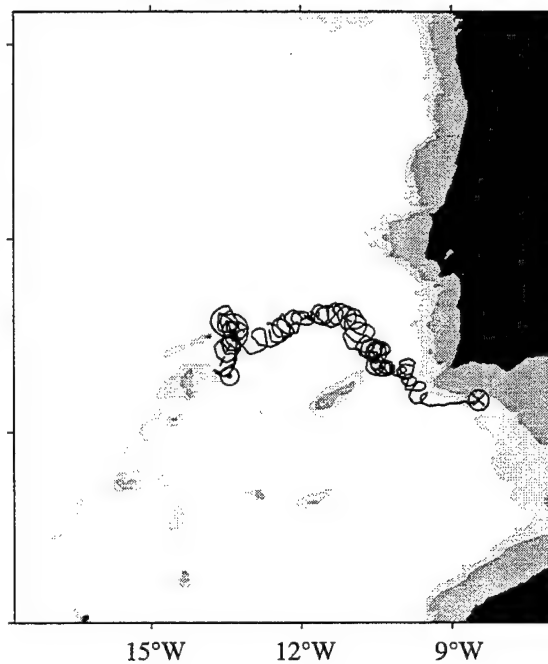




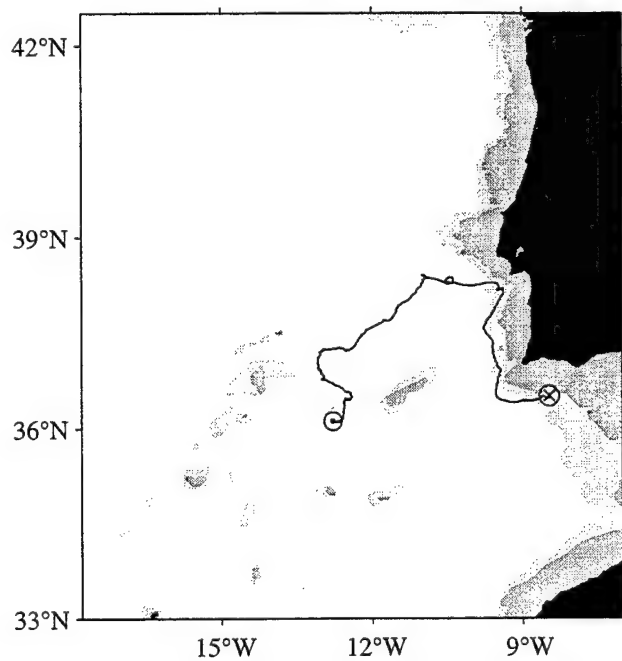
**K2305A: 940226: am115**



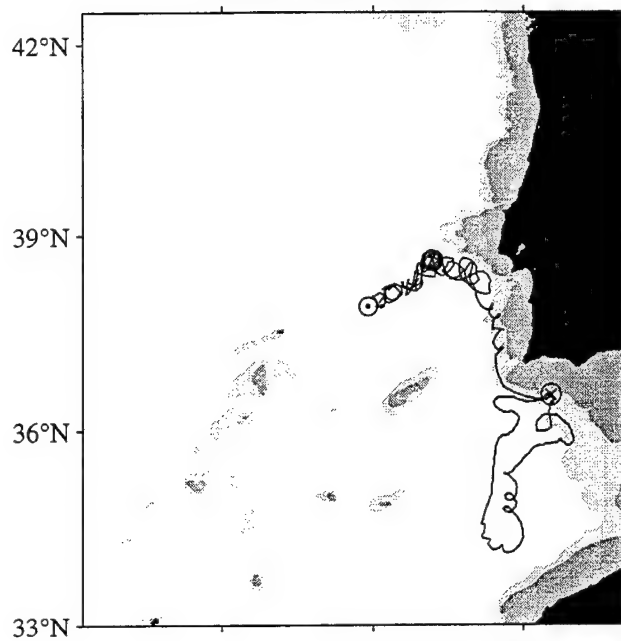
**K2307A: 940226: am129**



**K2307: 940226: am139**



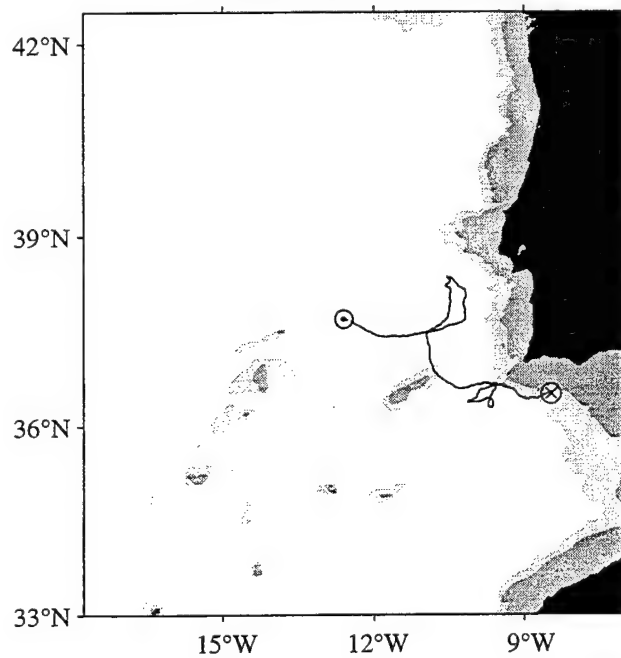
**K2406: 940305: am120b**



**K2406A: 940305: am121b**



**K2407: 940305: am106b**

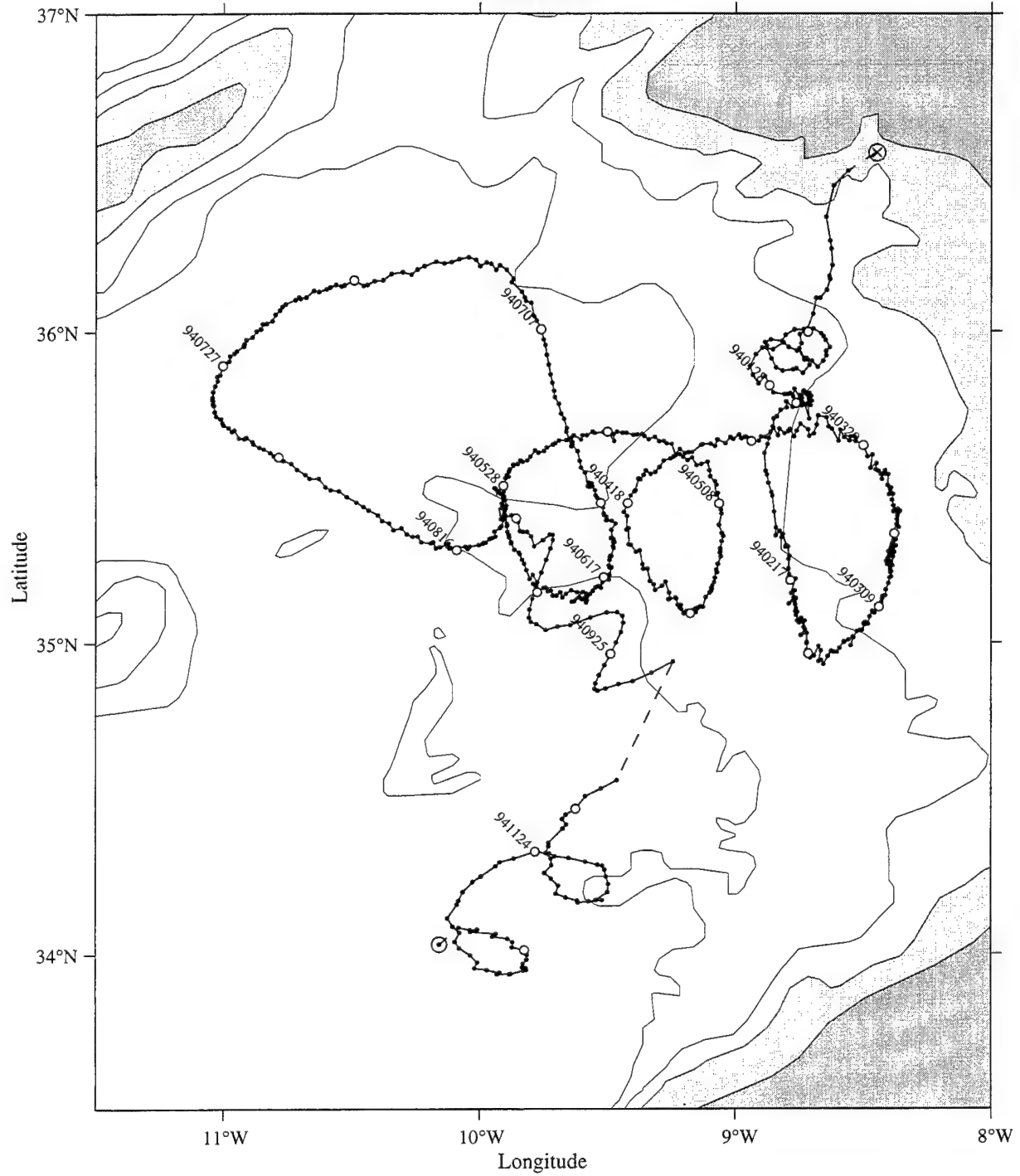


## **Appendix B:**

### **Individual float tracks and property plots.**

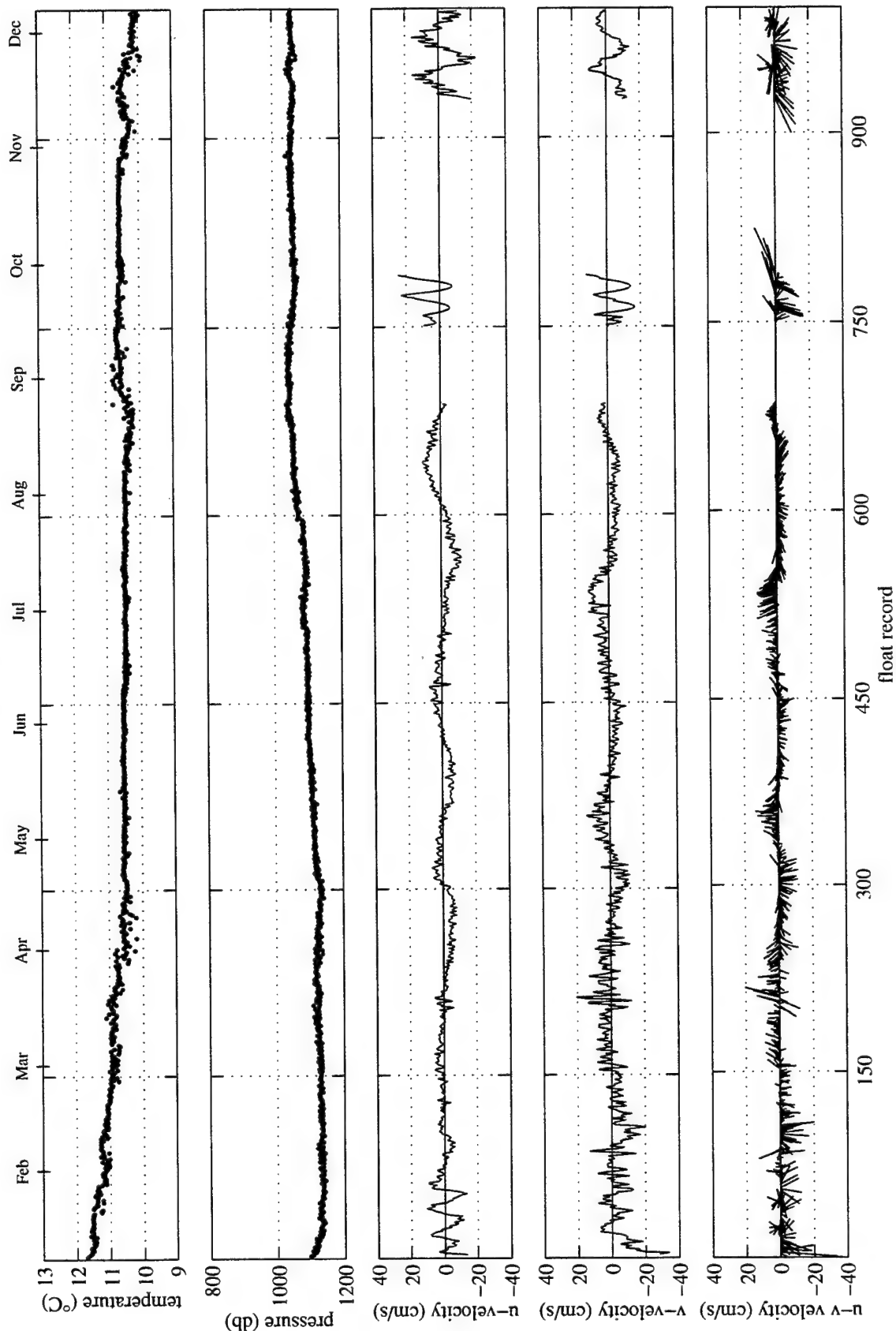
We present individual float tracks and temperature, pressure, and velocity plots. Float launch and surface positions and tracks are marked the same as in the track gallery plots. In addition, each record is marked with a black dot, and every 10 days is marked by a white dot. Every 20<sup>th</sup> day (every other white dot) is marked with the date, represented as 'yymmdd'. If the float mission was less than 90 days, the date is marked at 10-day intervals, with each white dot. Float property plots show temperature, pressure, u-velocity, v-velocity, and stick diagrams representing u-v velocity. The lower x-axis marks the float record number, which is once every 8 hours for all floats except float am134, which recorded data once every 16 hours. The 1000 and 2000 meter isobaths are shown in shades of gray; the 3000 and 4000 meter isobaths are marked by unshaded contours.

# am100

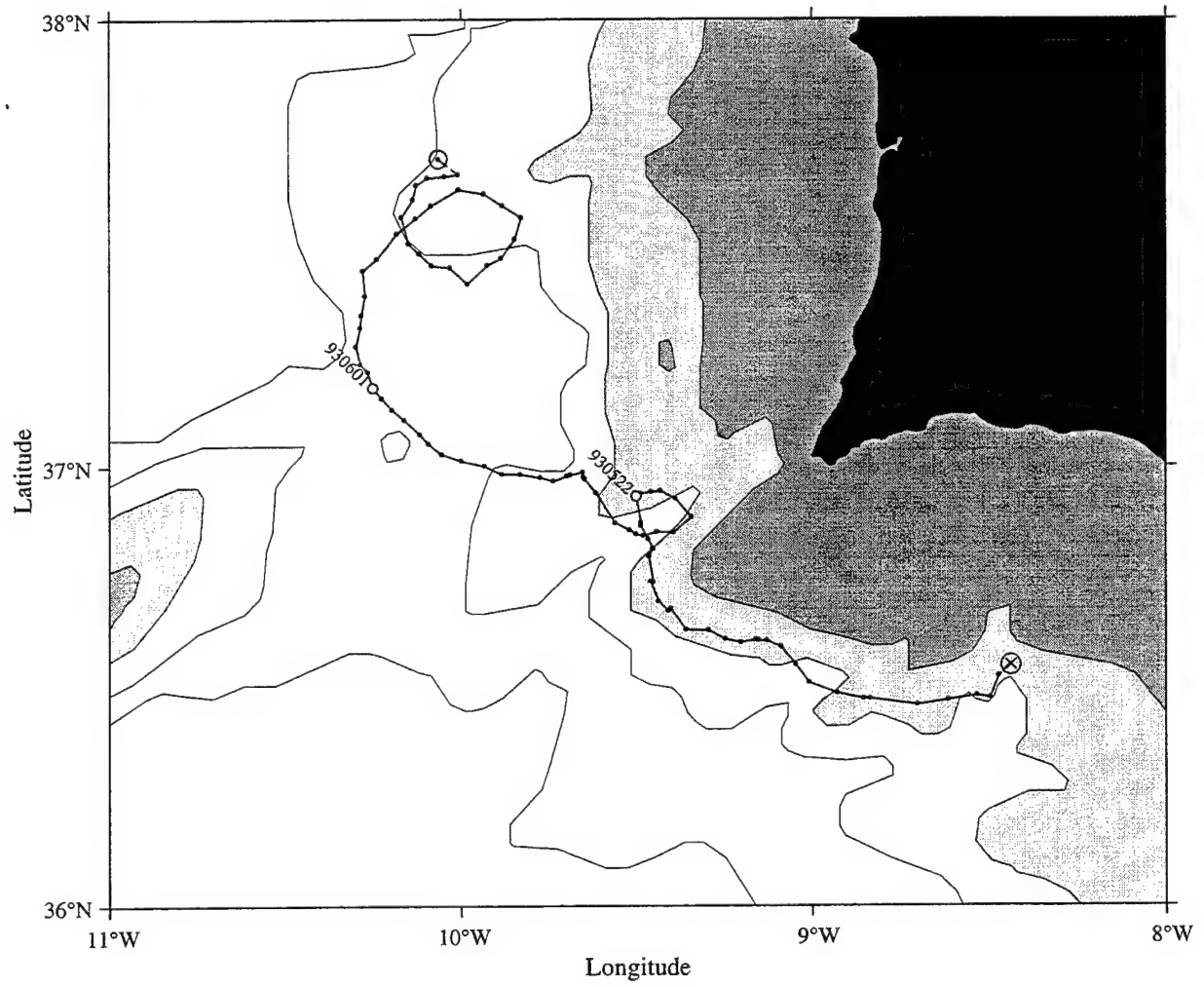


# am100

1994



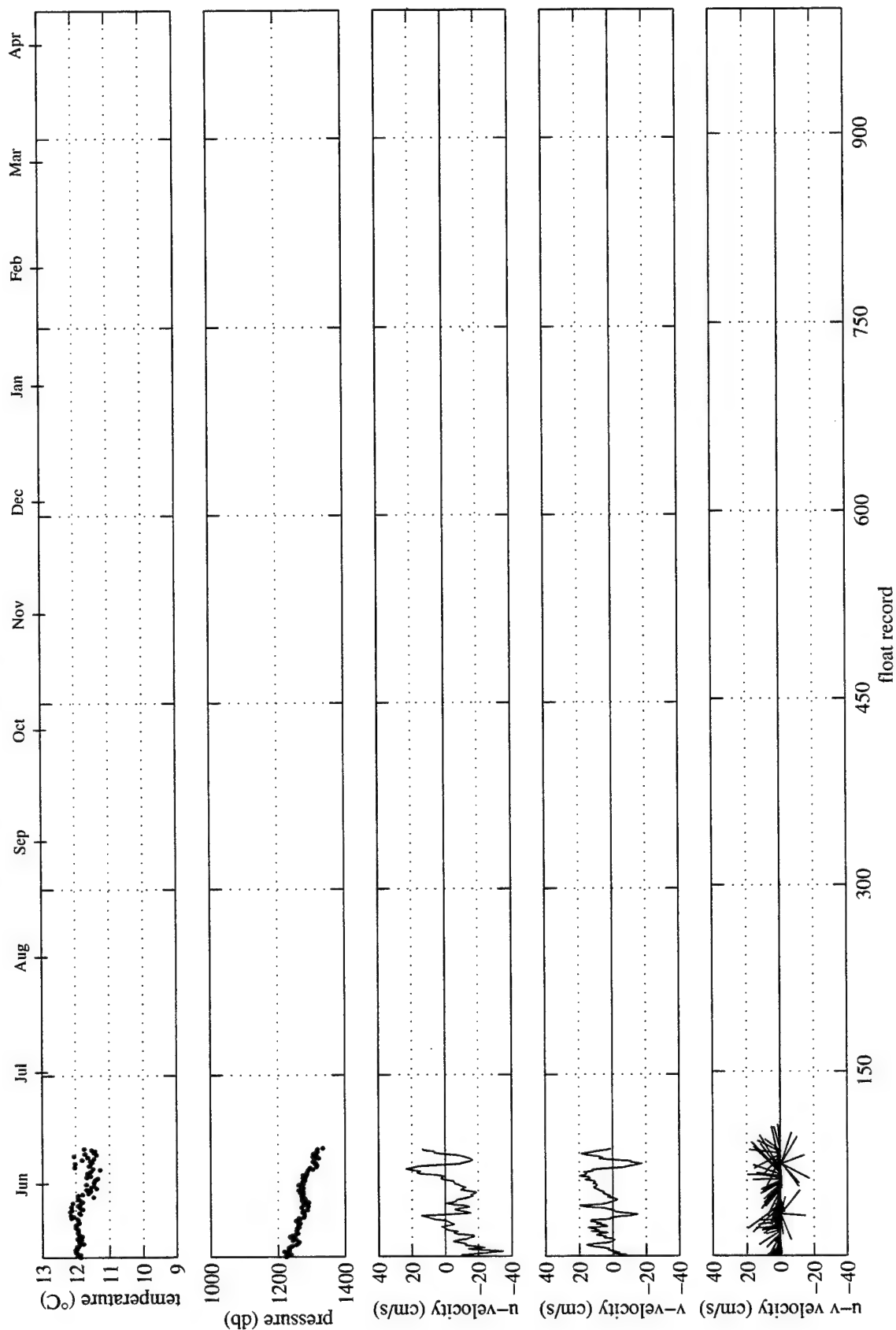
am101



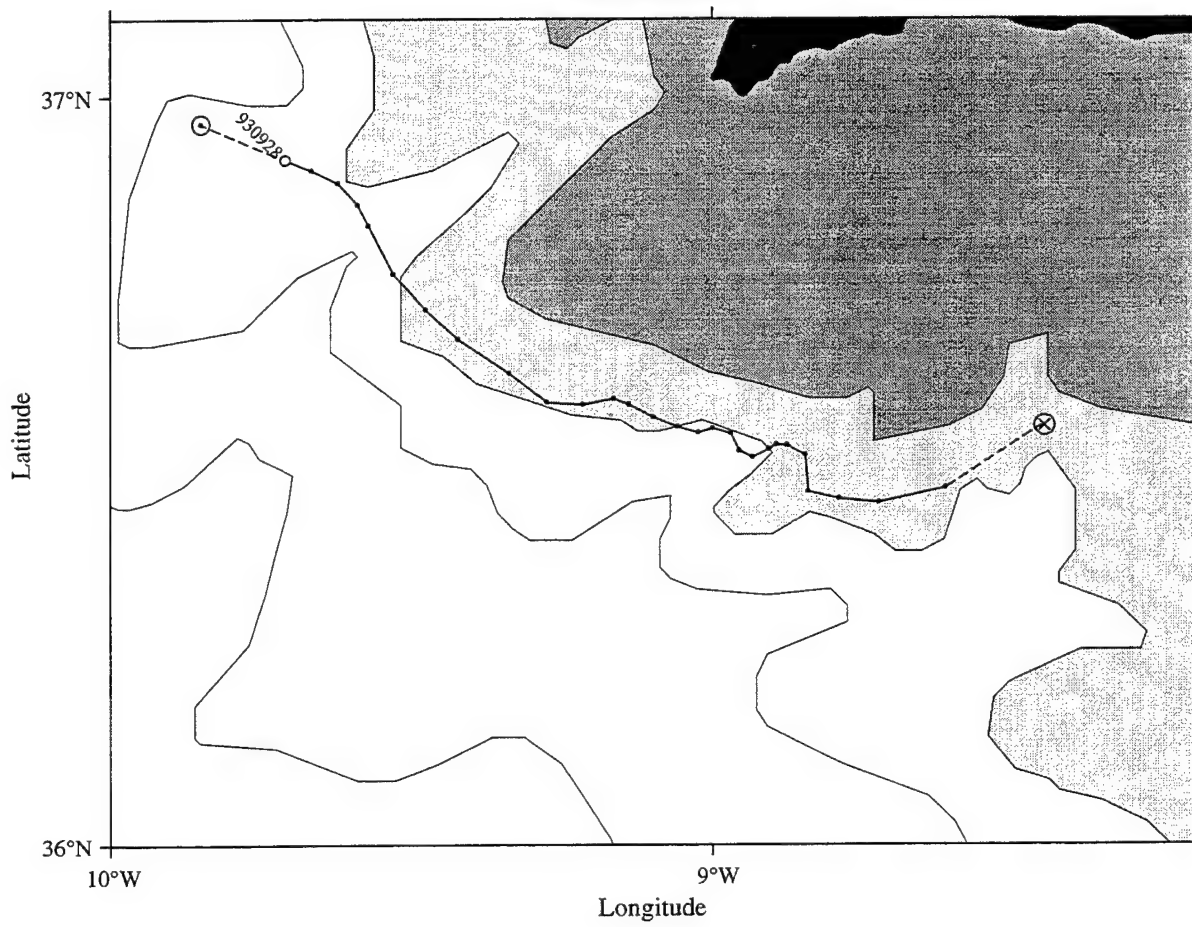
# am101

1993

19



am102

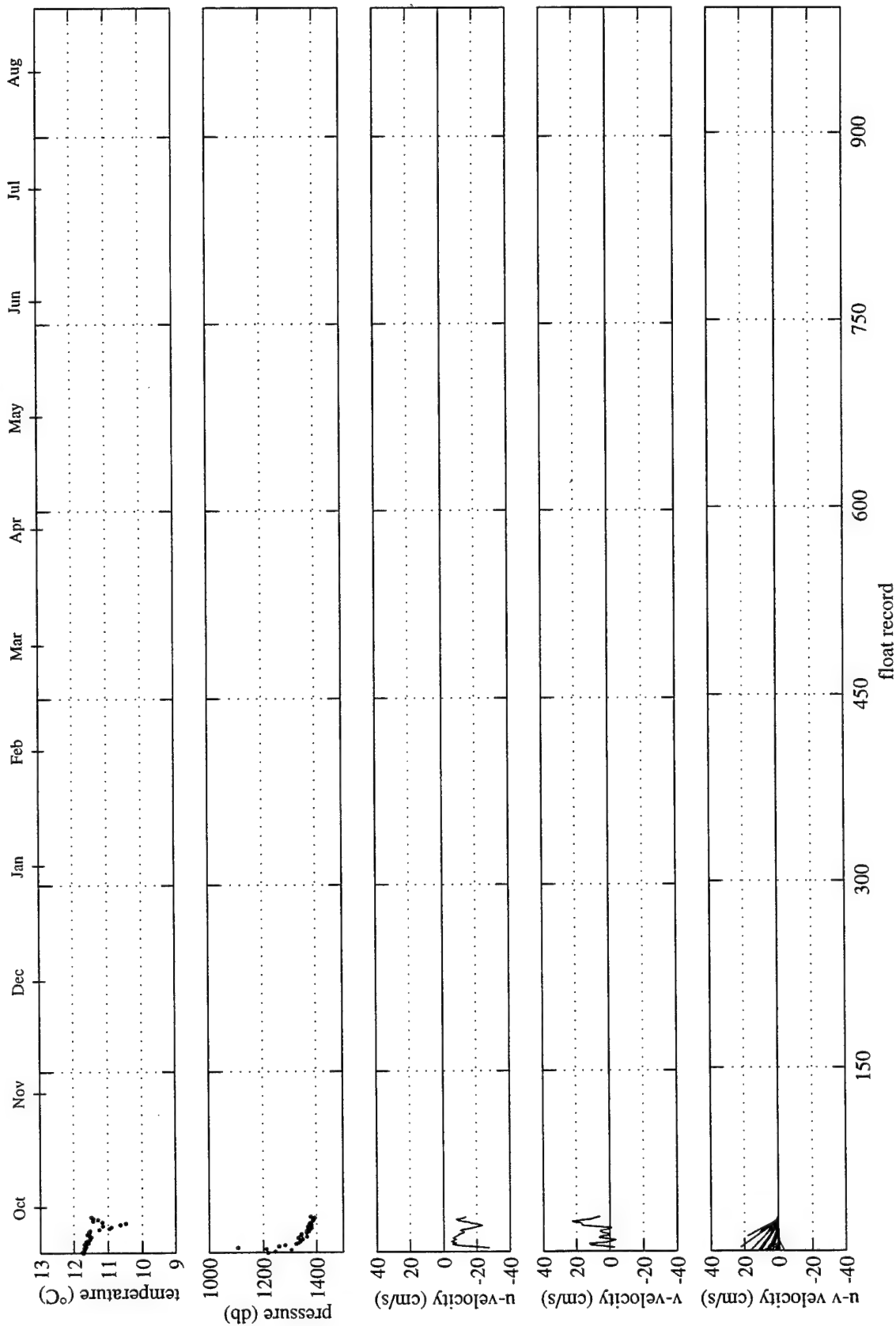


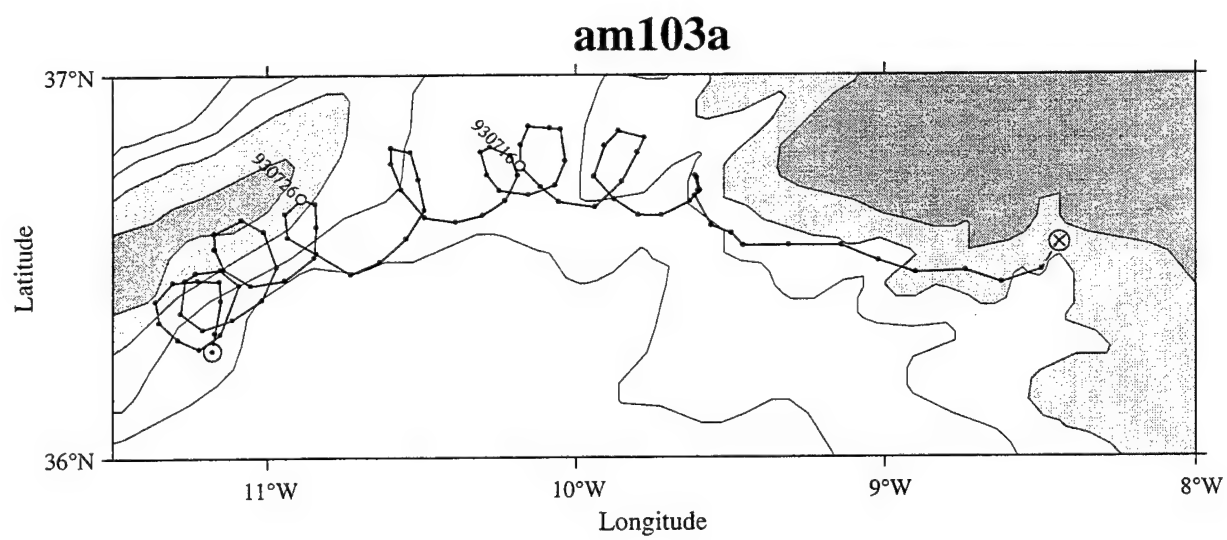


# am102

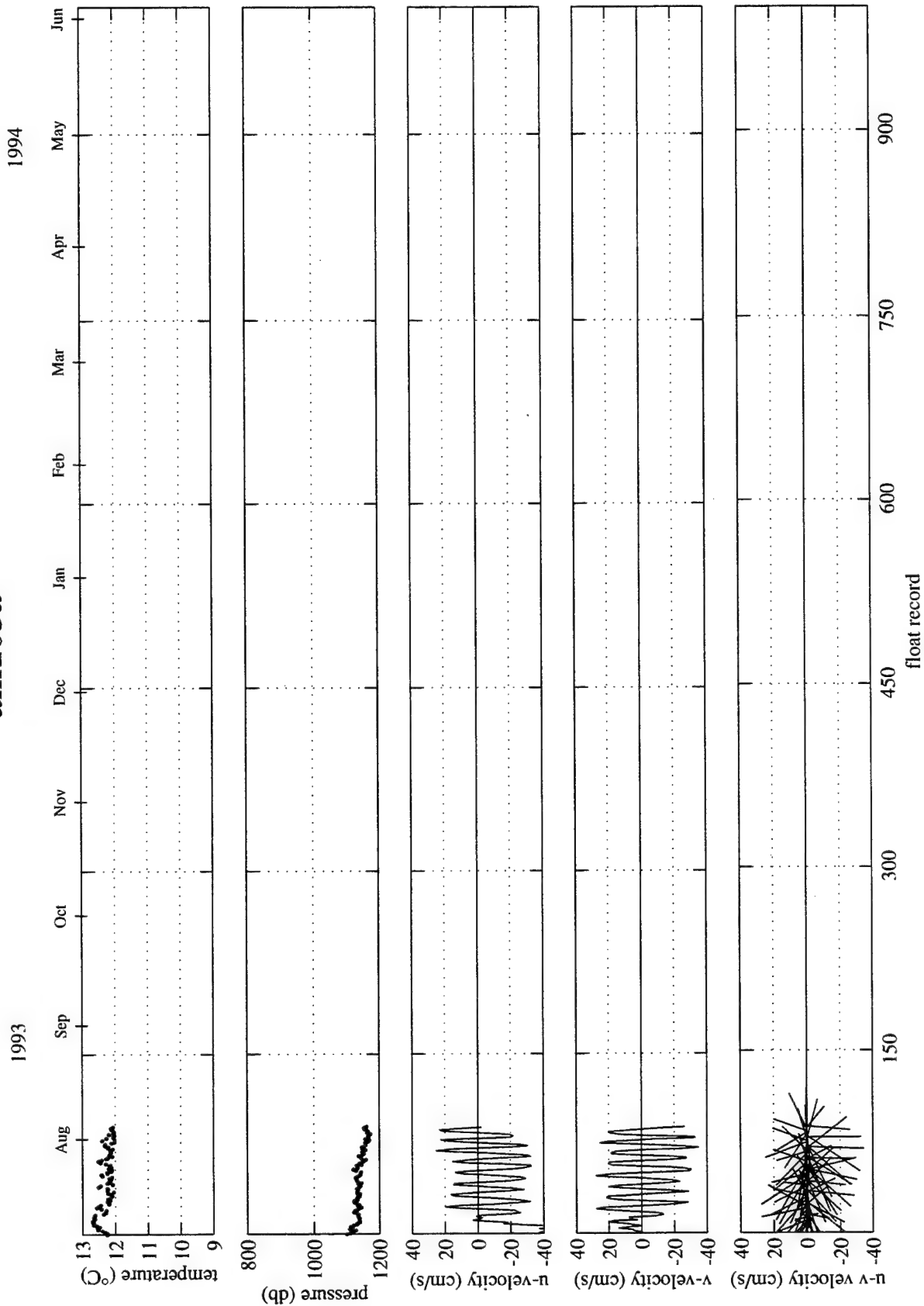
1993

1994

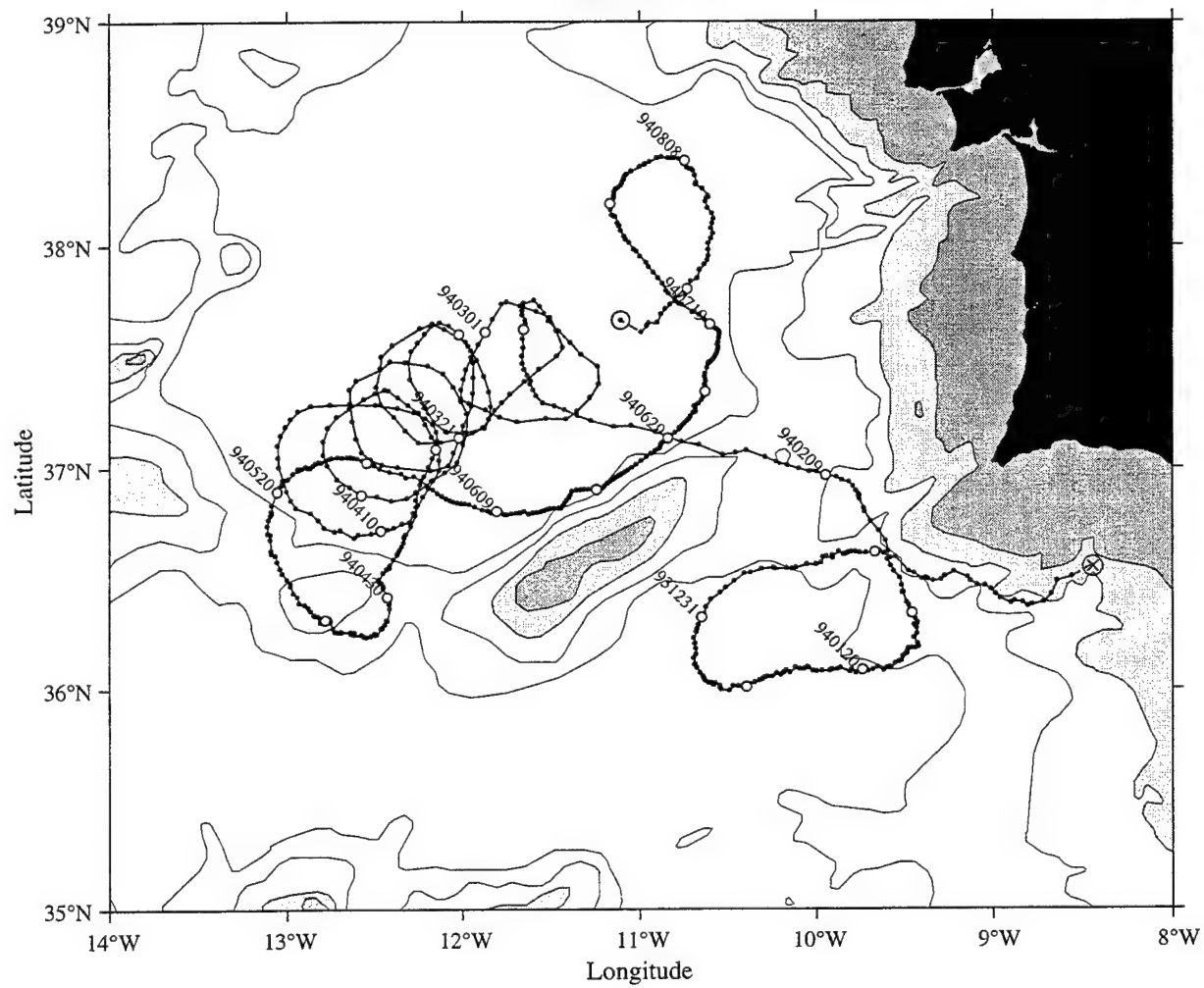




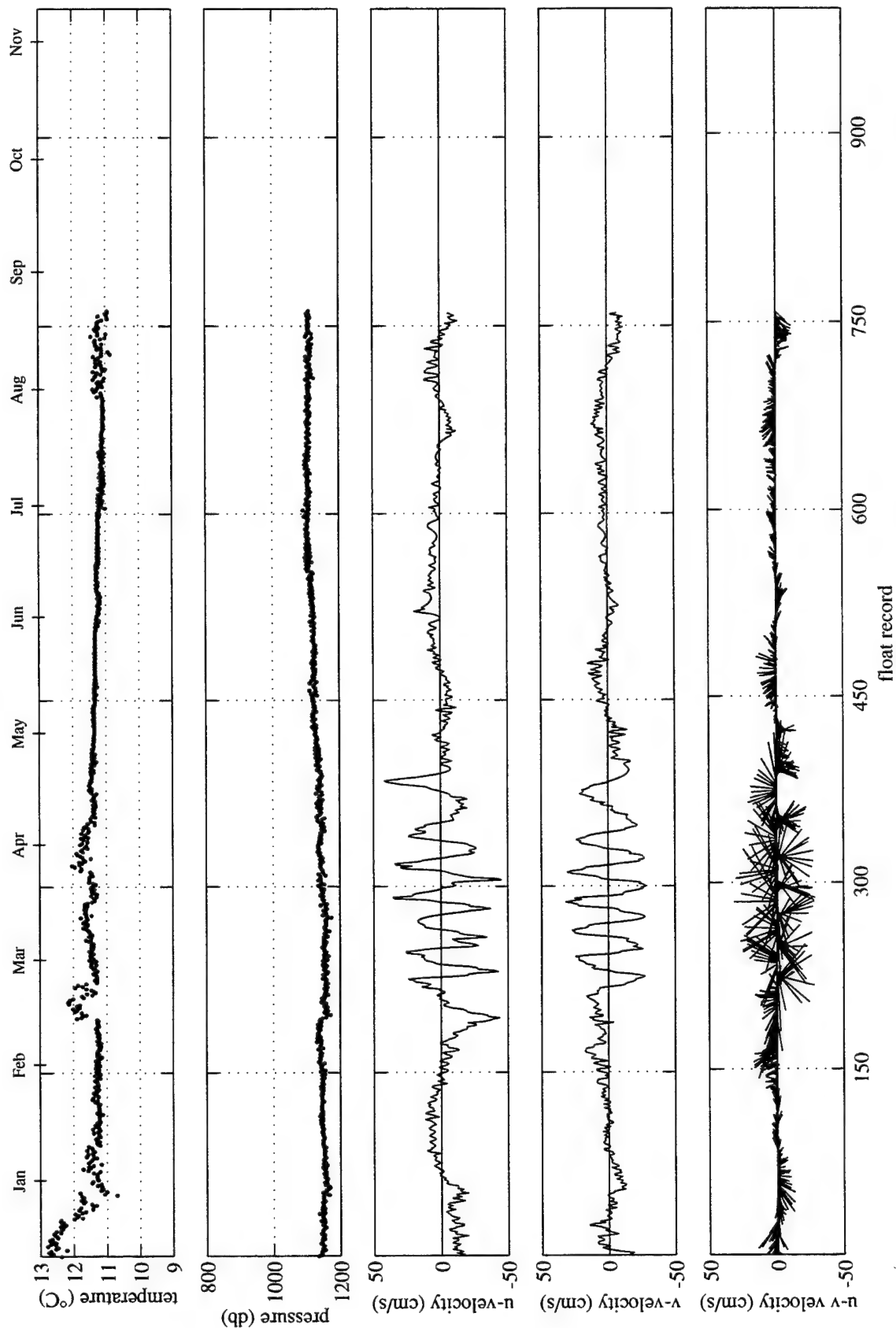
# am103a

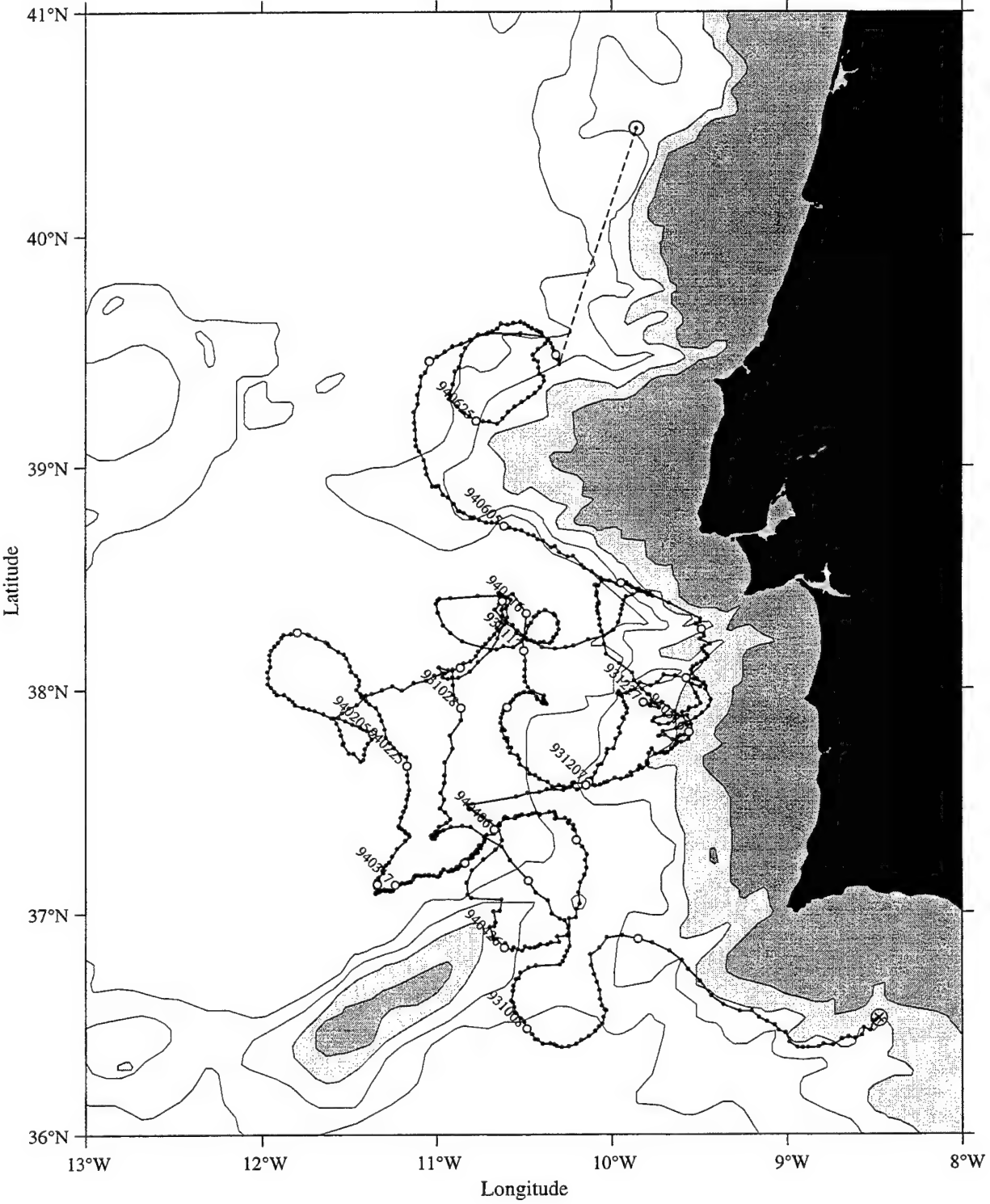


am103b



# am103b 1994

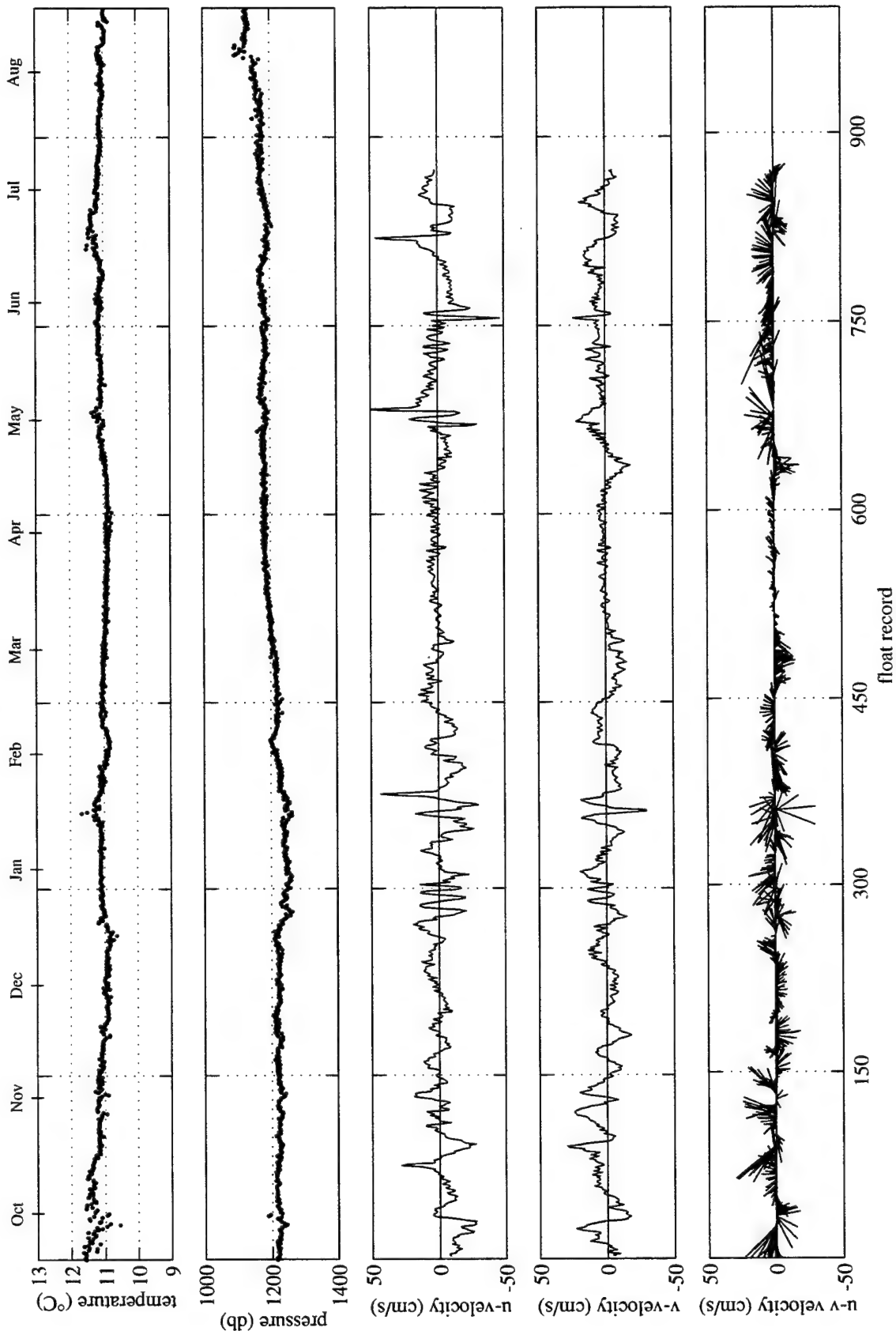


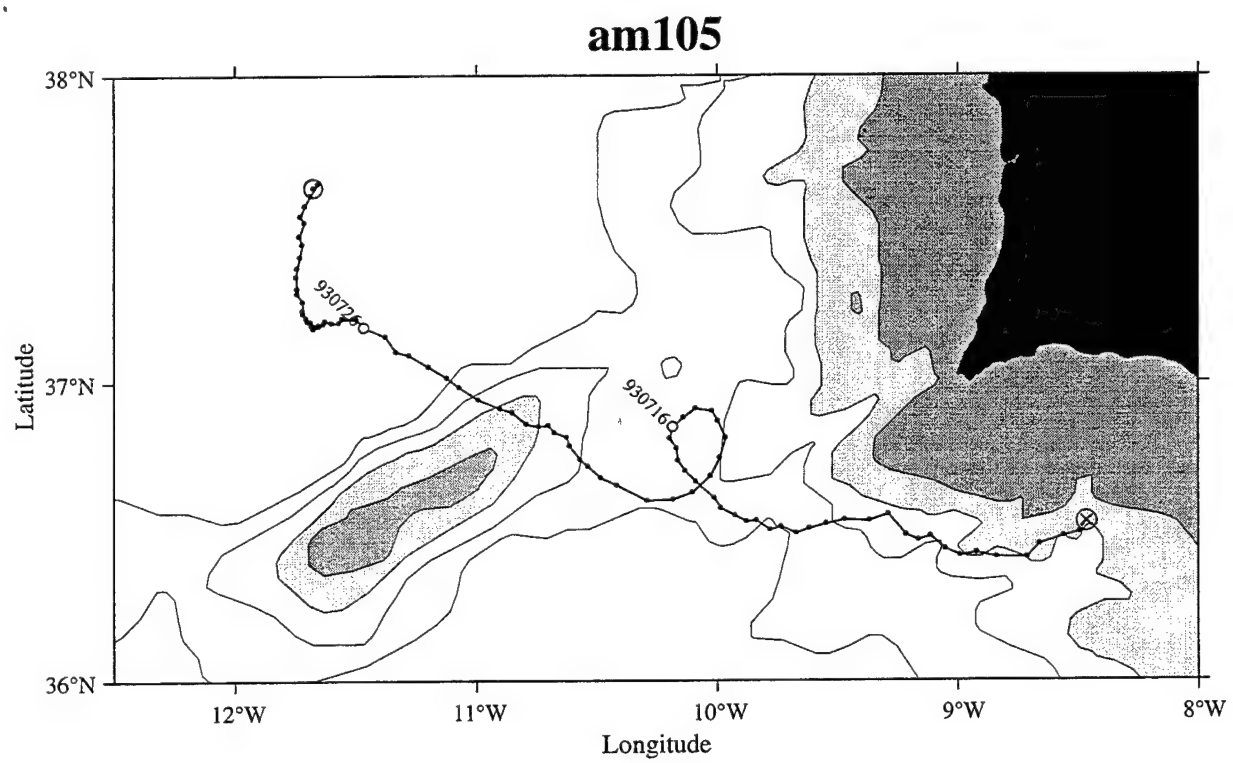
**am104**

# am104

1993

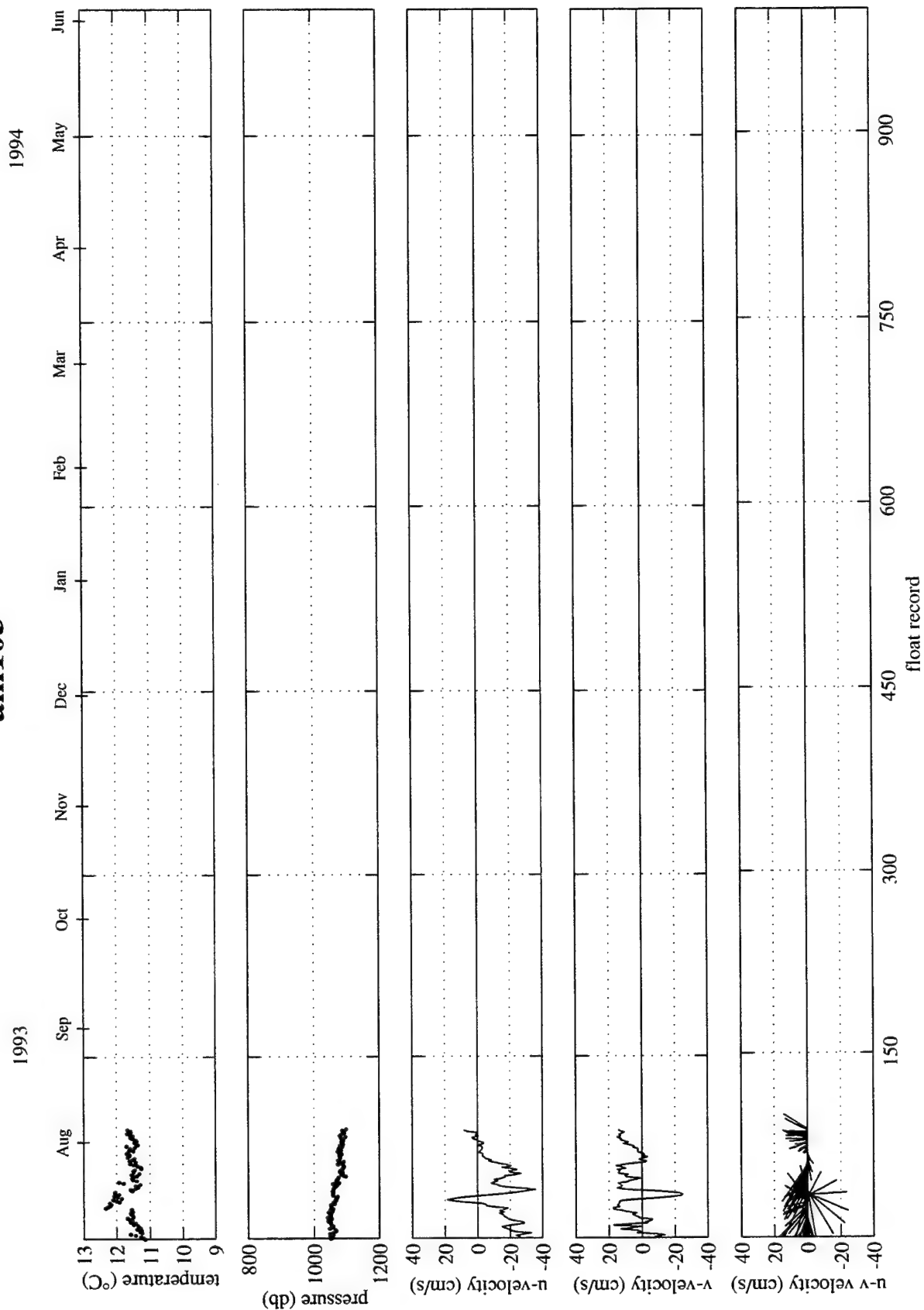
1994



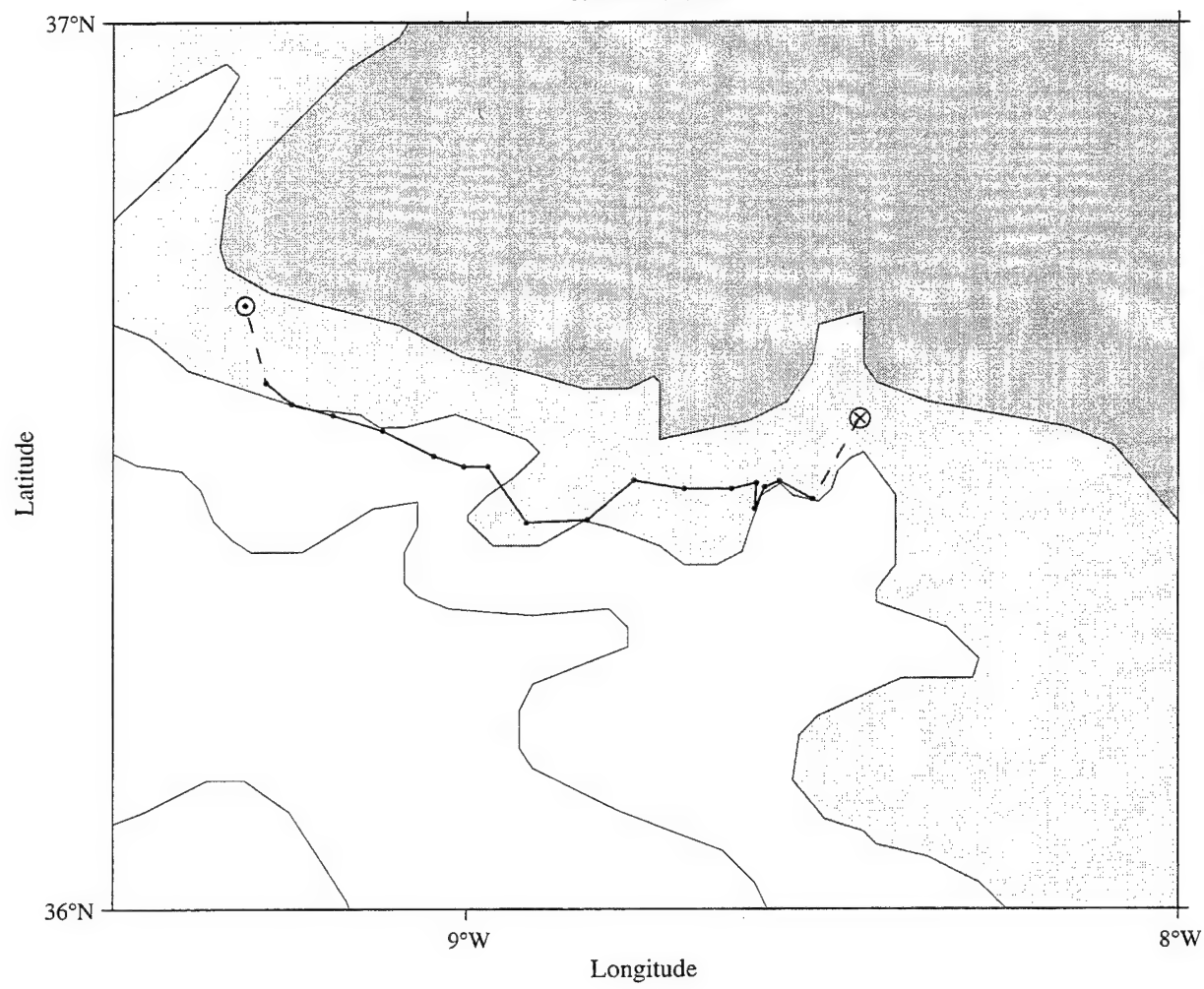




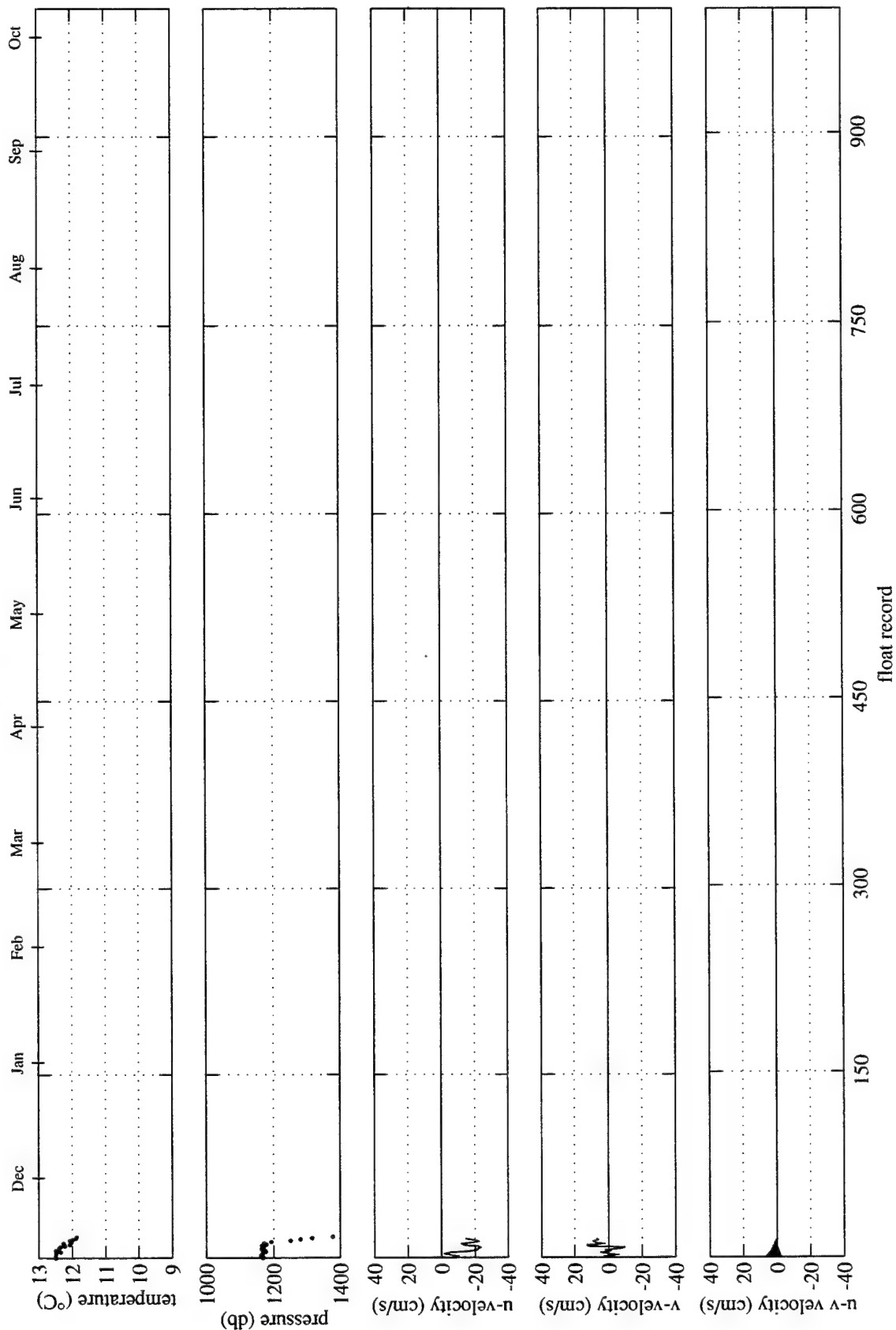
# am105



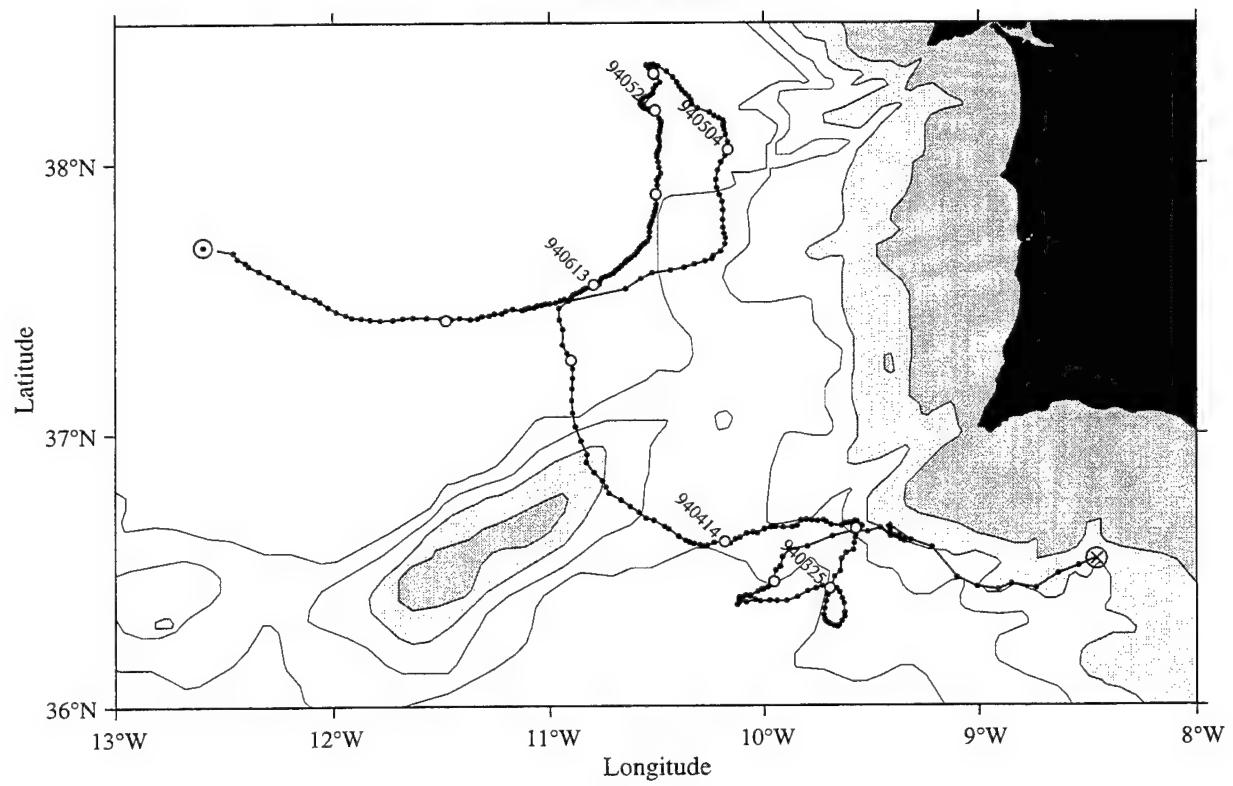
**am106a**



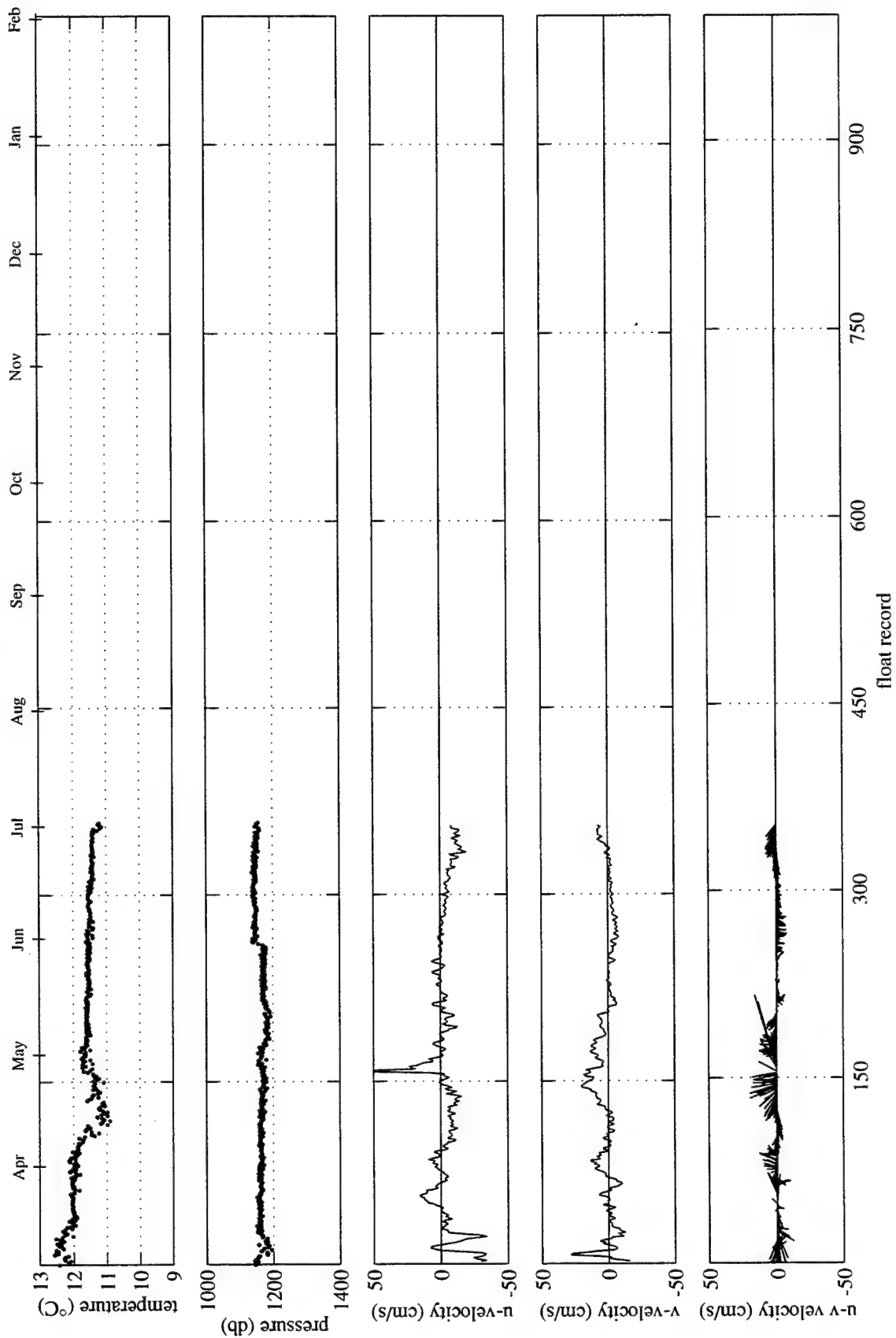
# am106a 1994



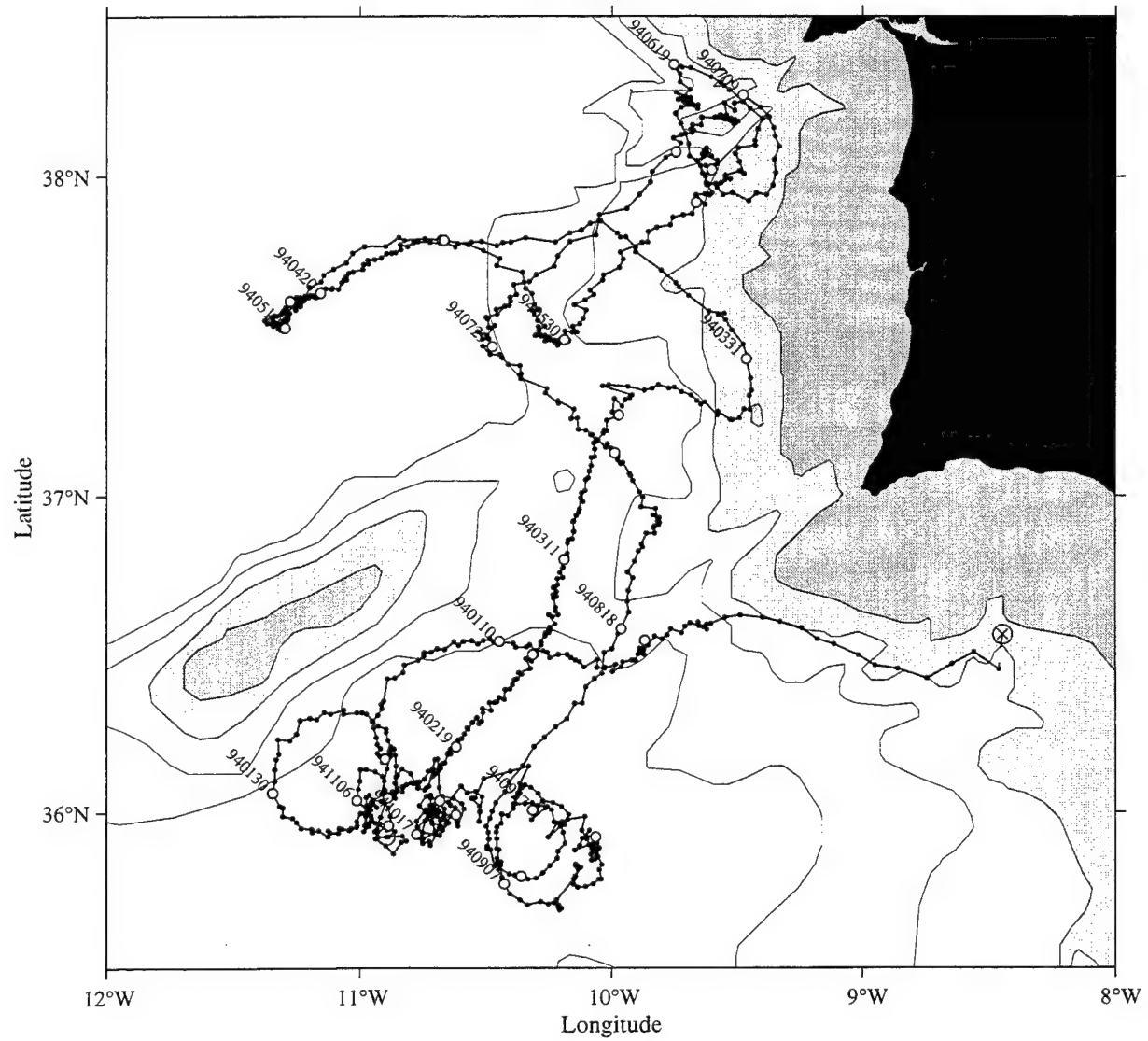
**am106b**



# am106b 1994

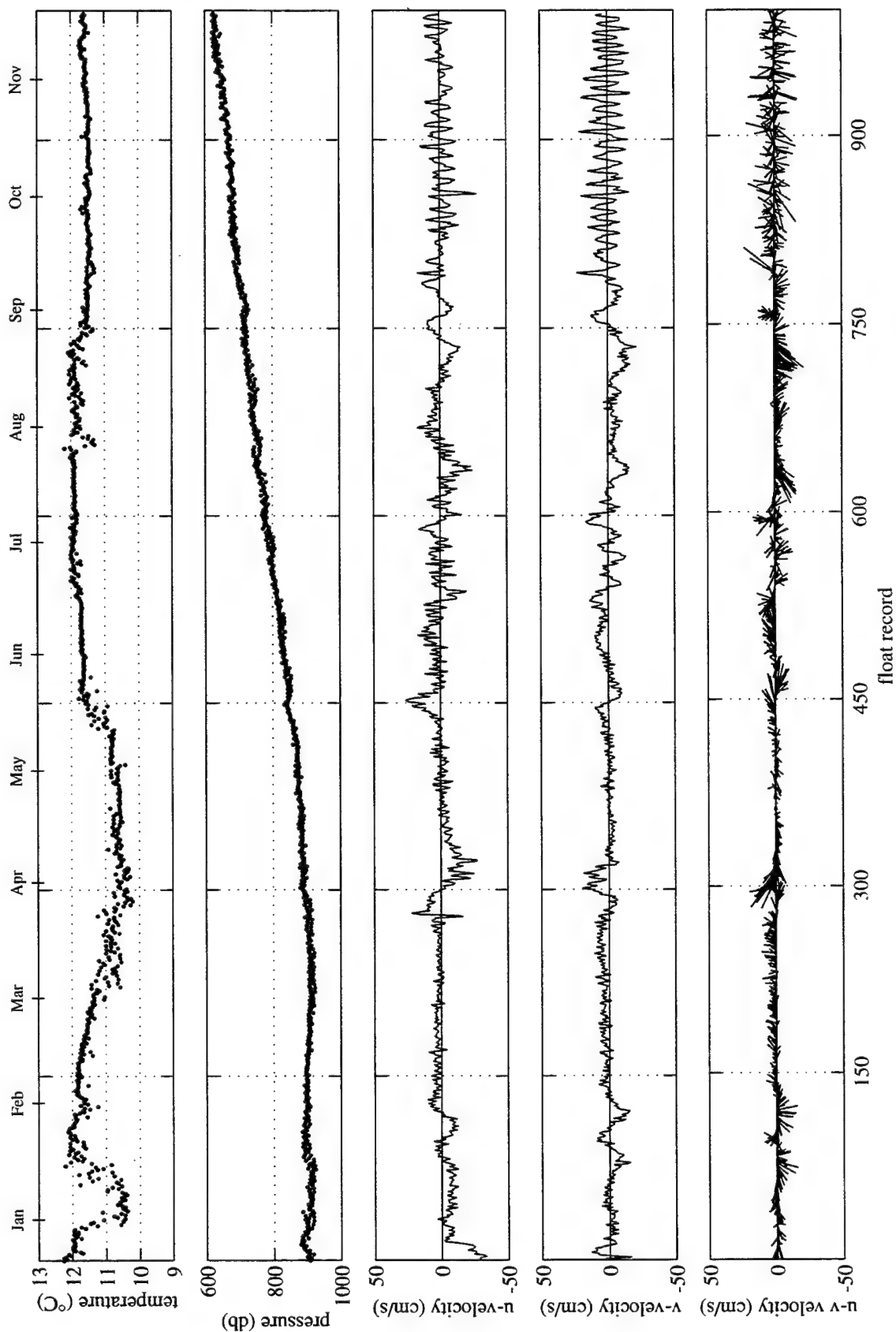


am107

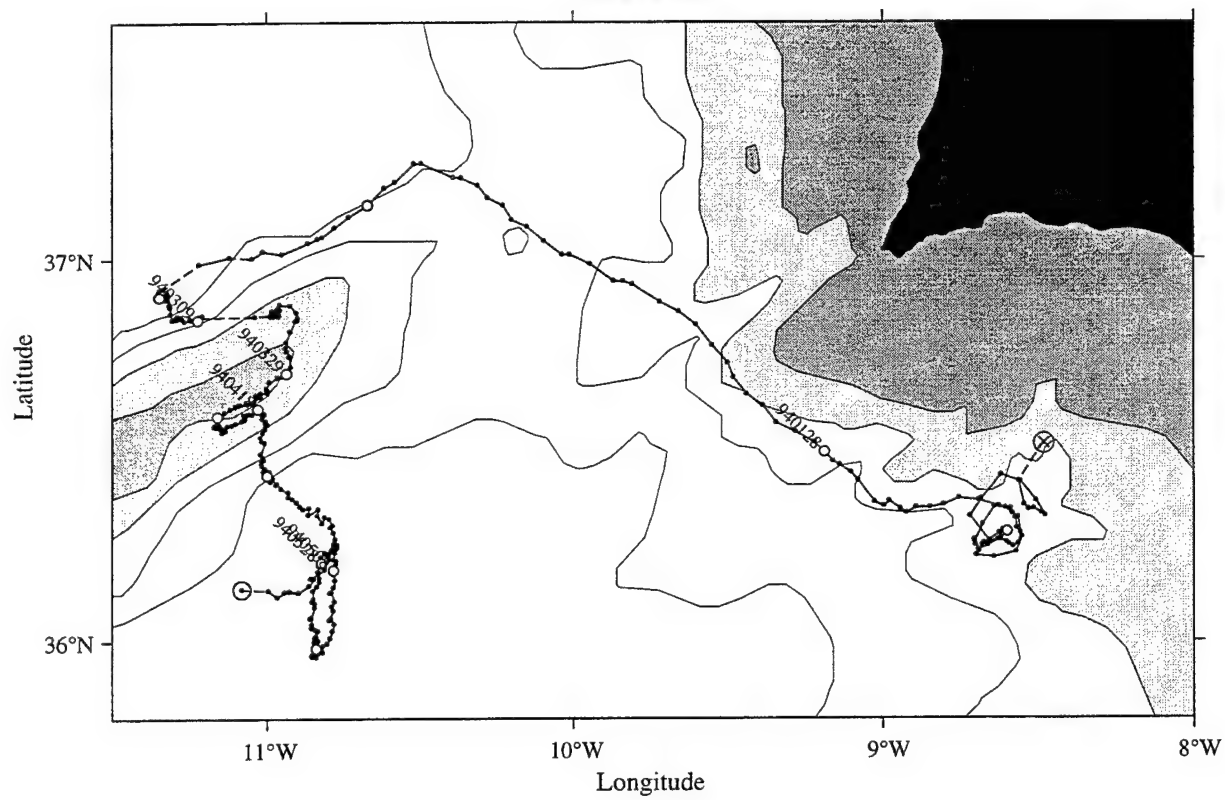


# am107

1994



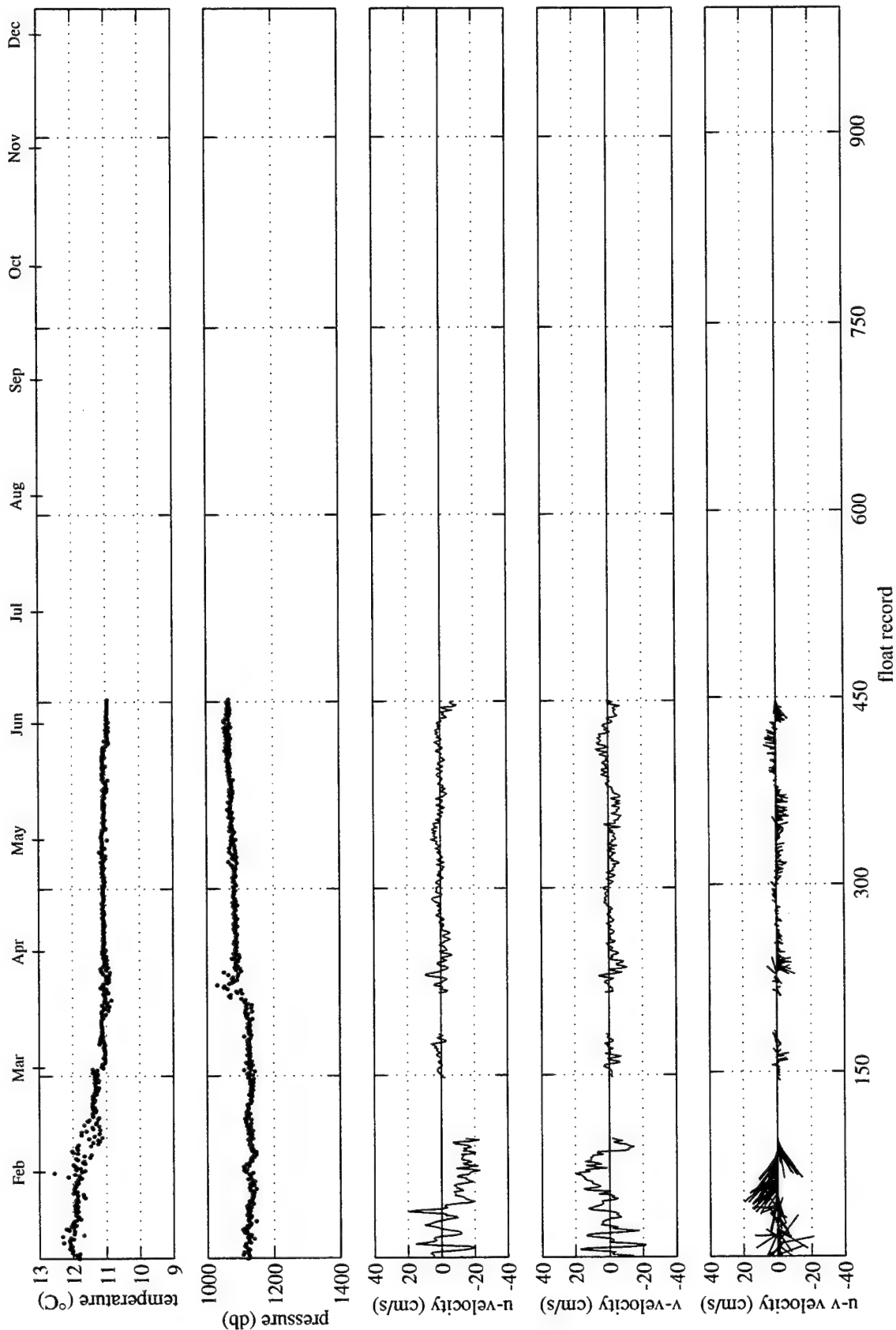
am108



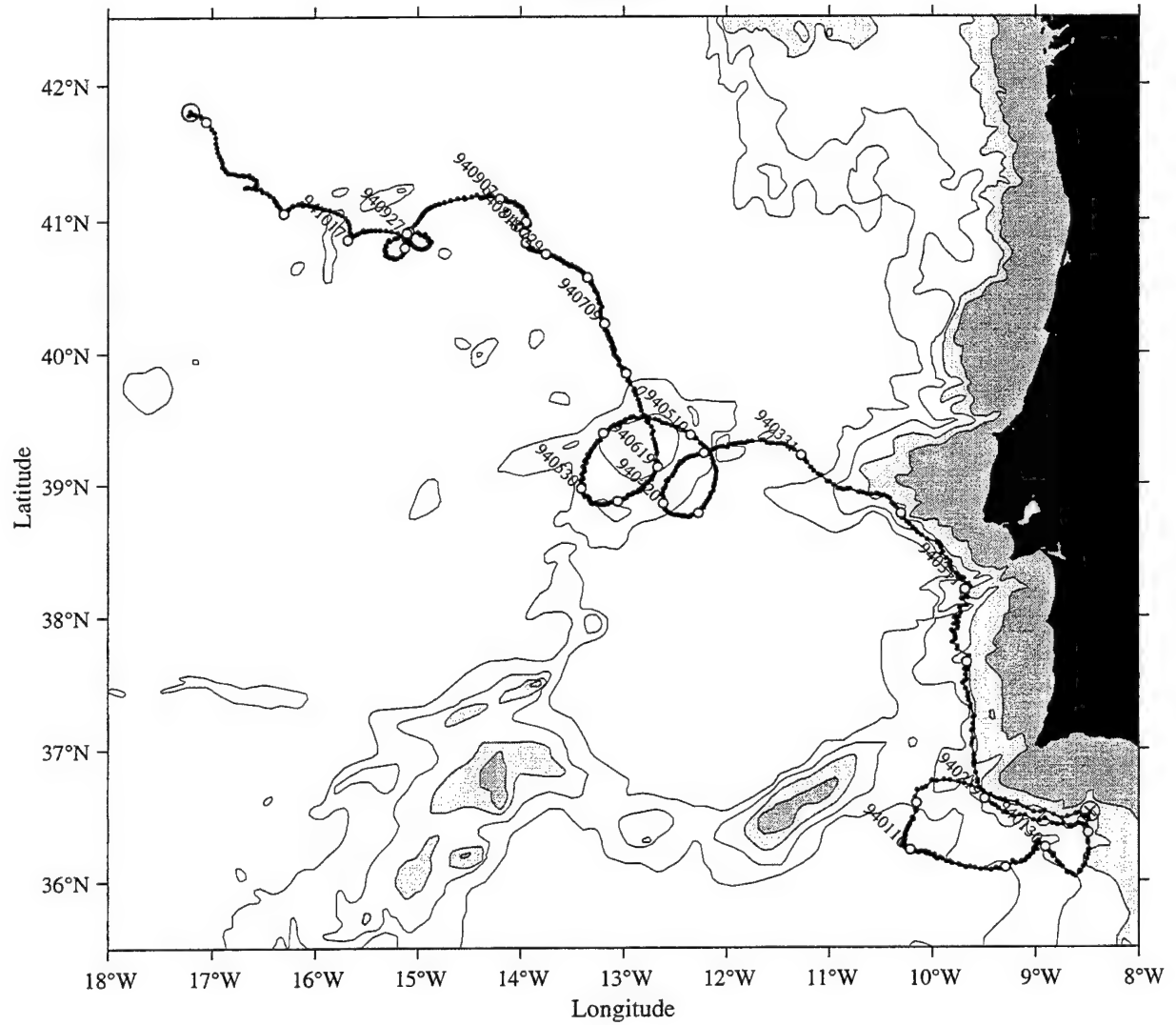


# am108

1994

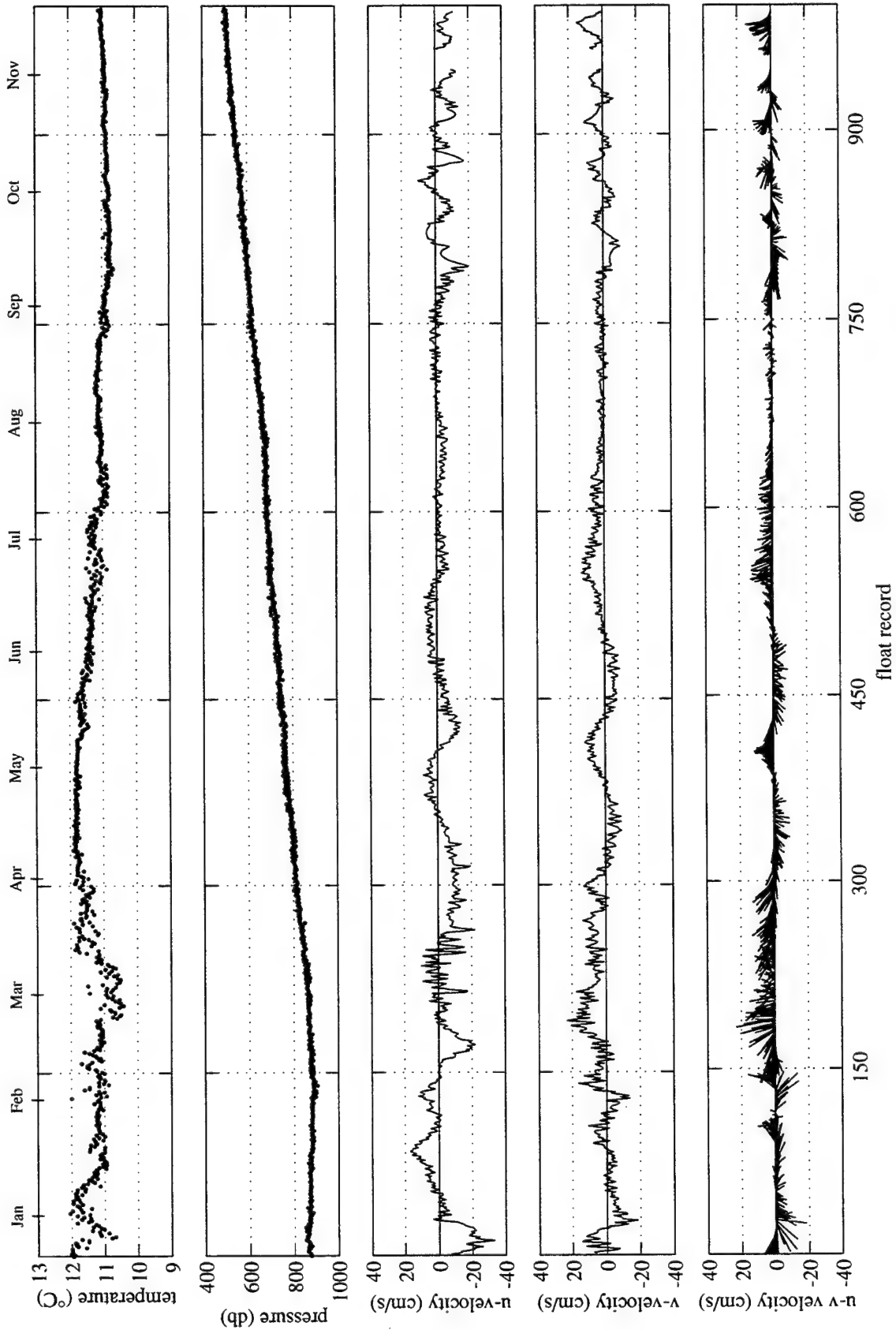


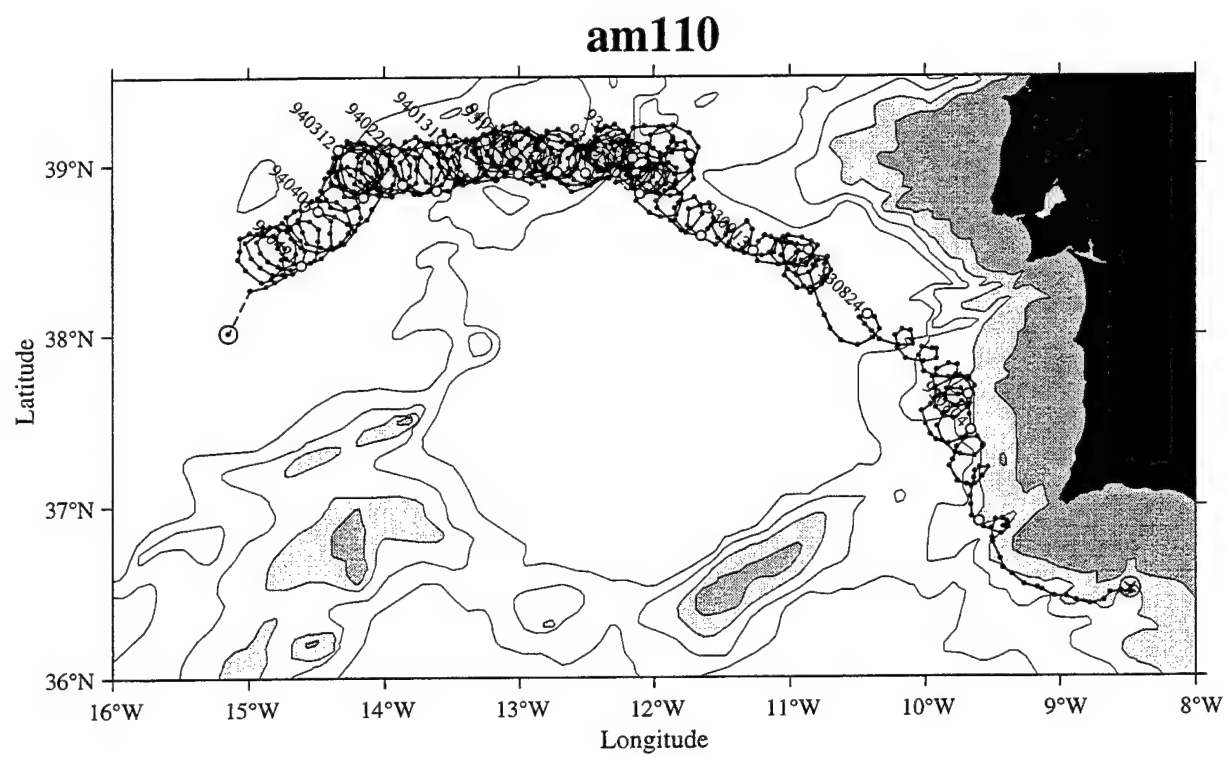
am109



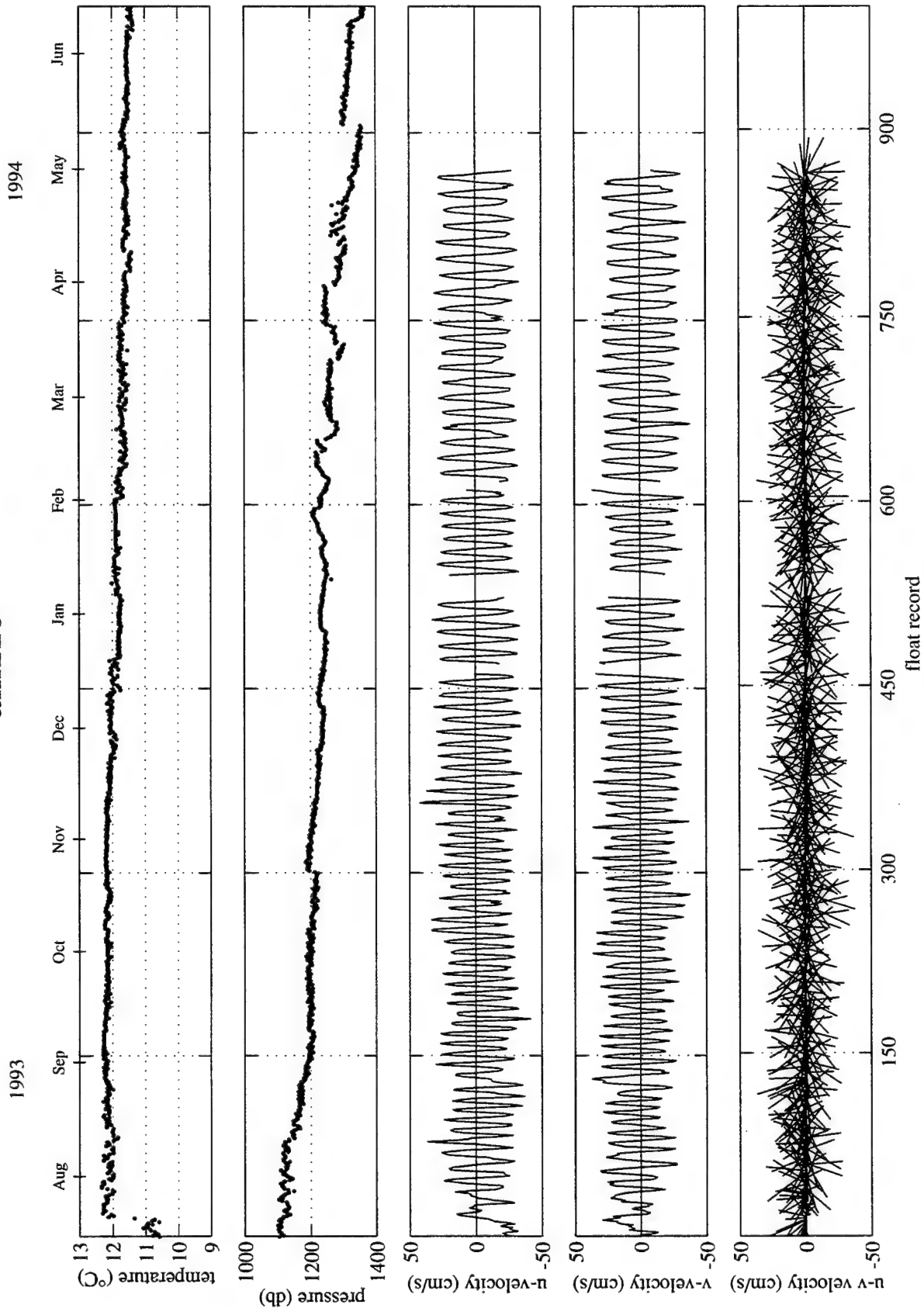
# am109

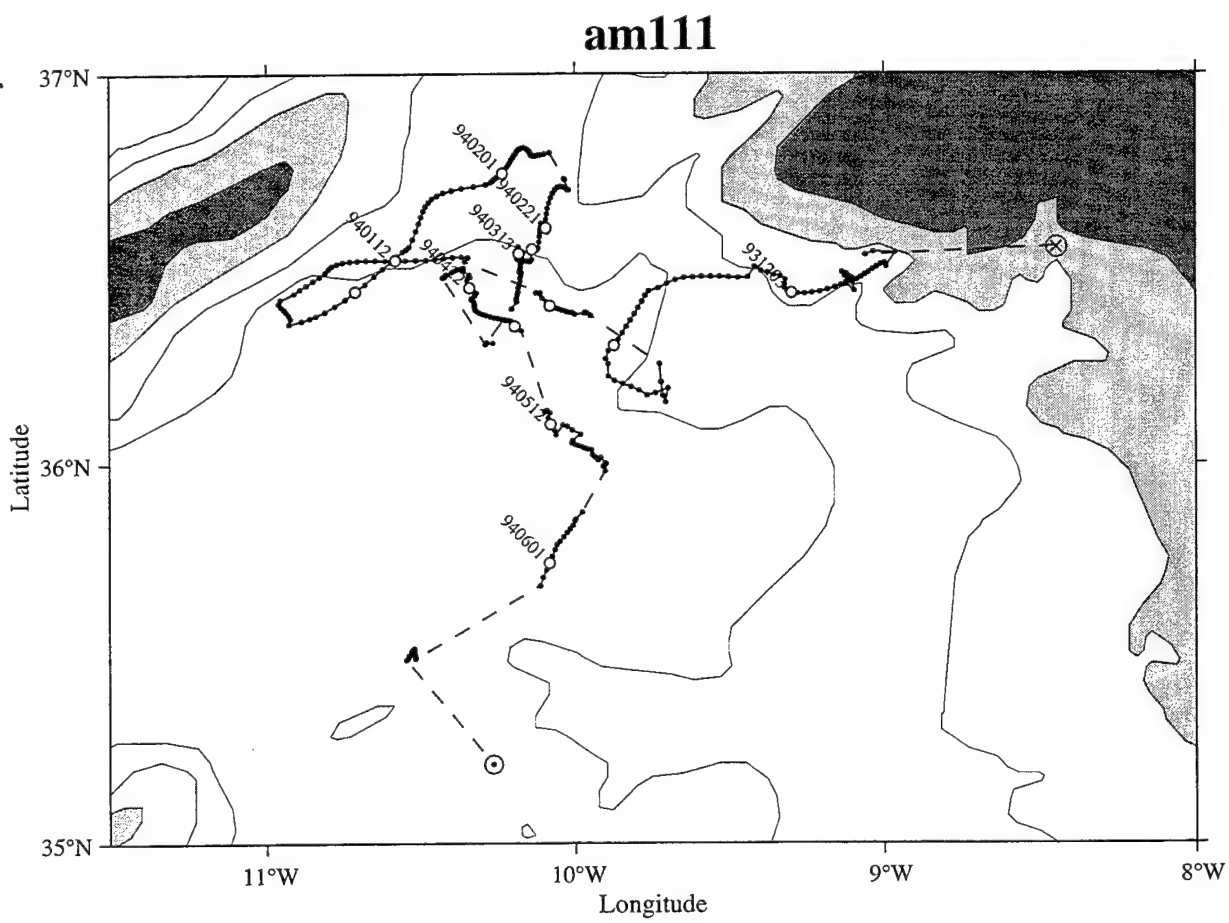
1994



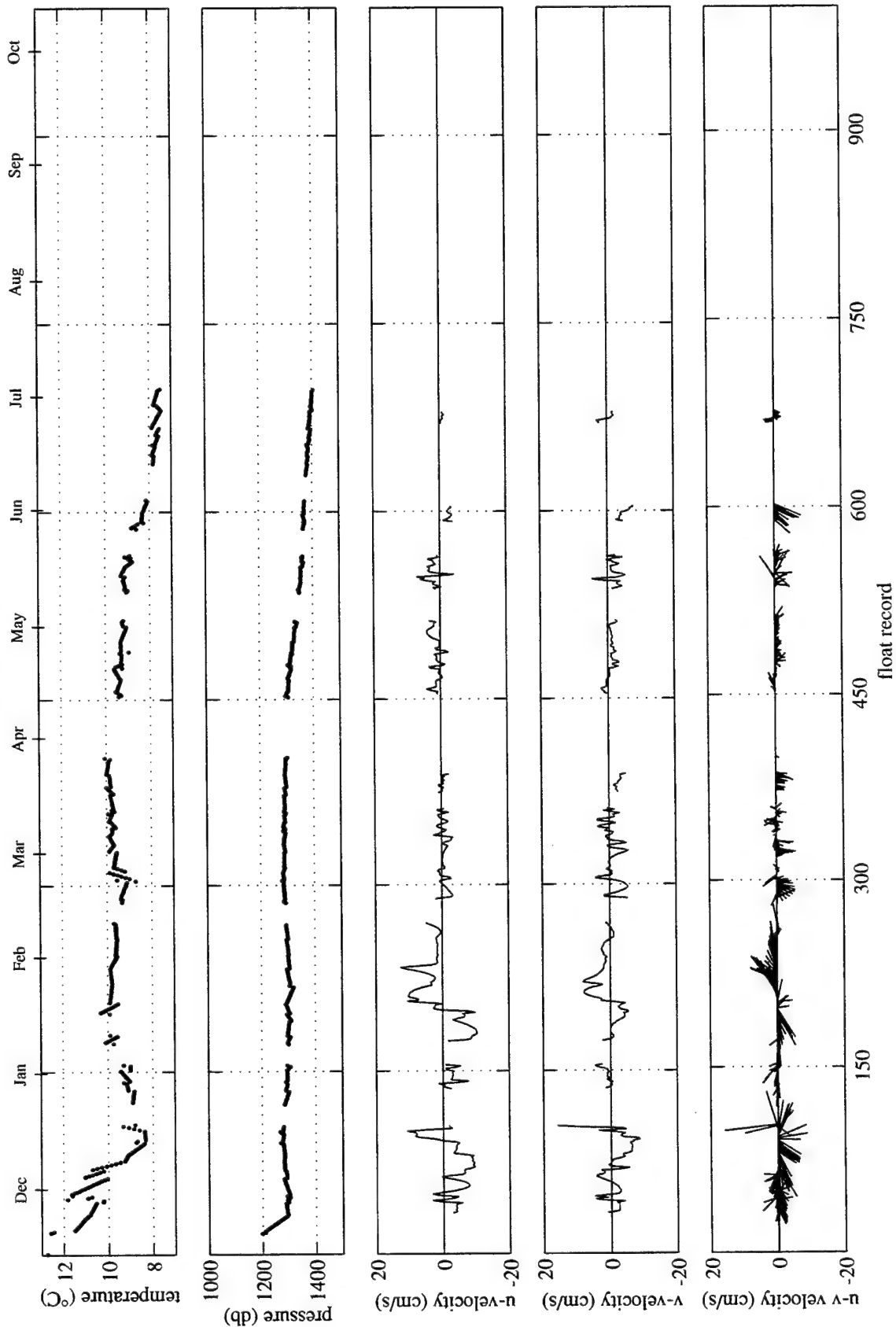


# am110

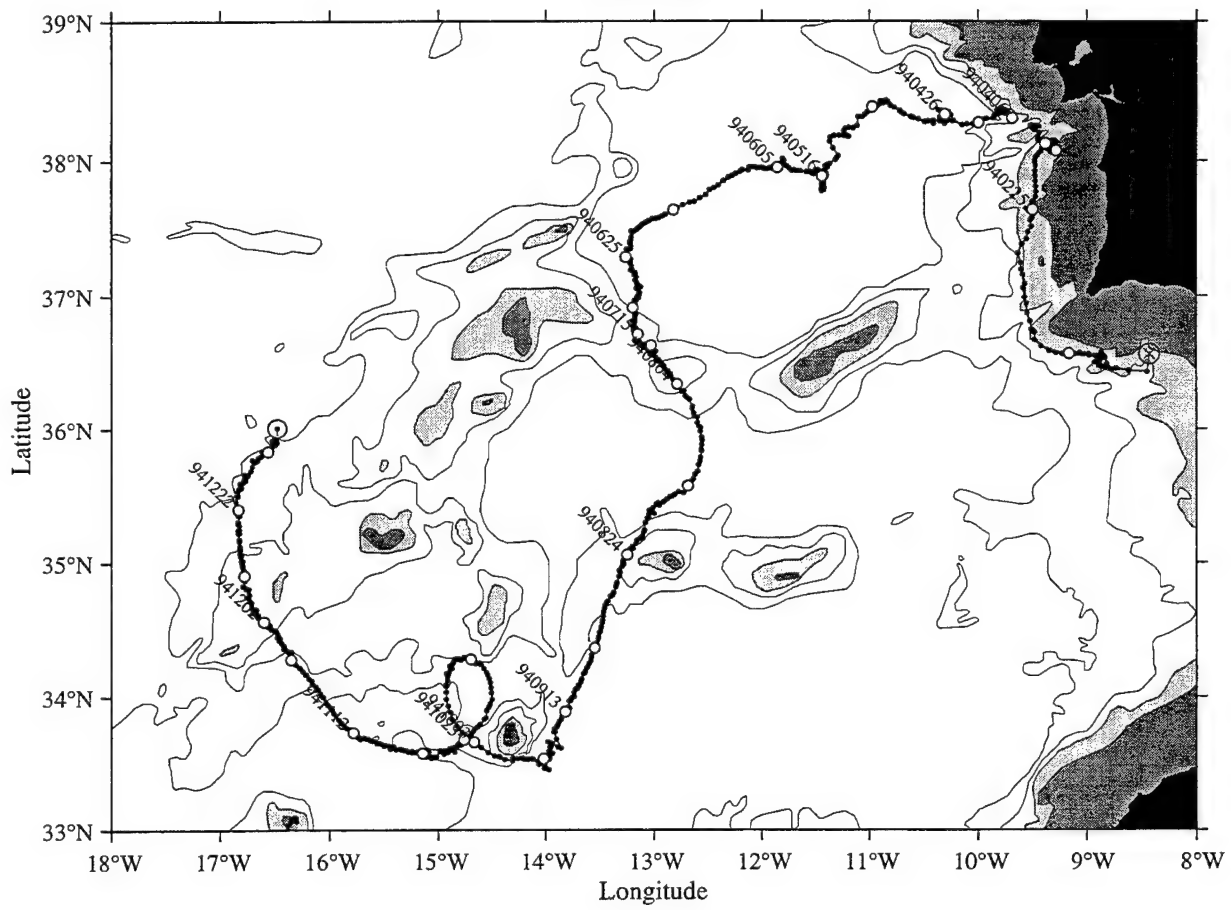




# am111 1994



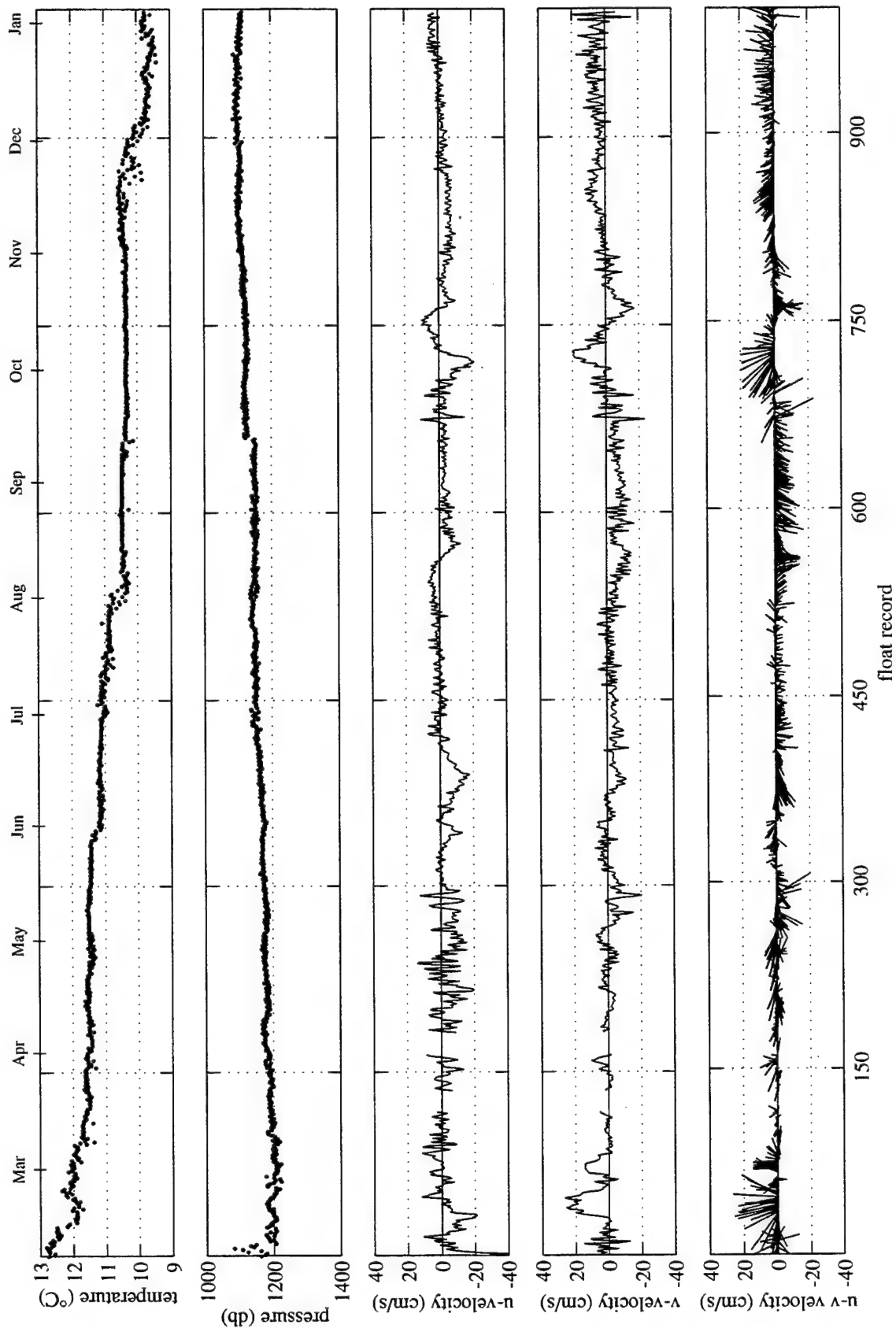
am112



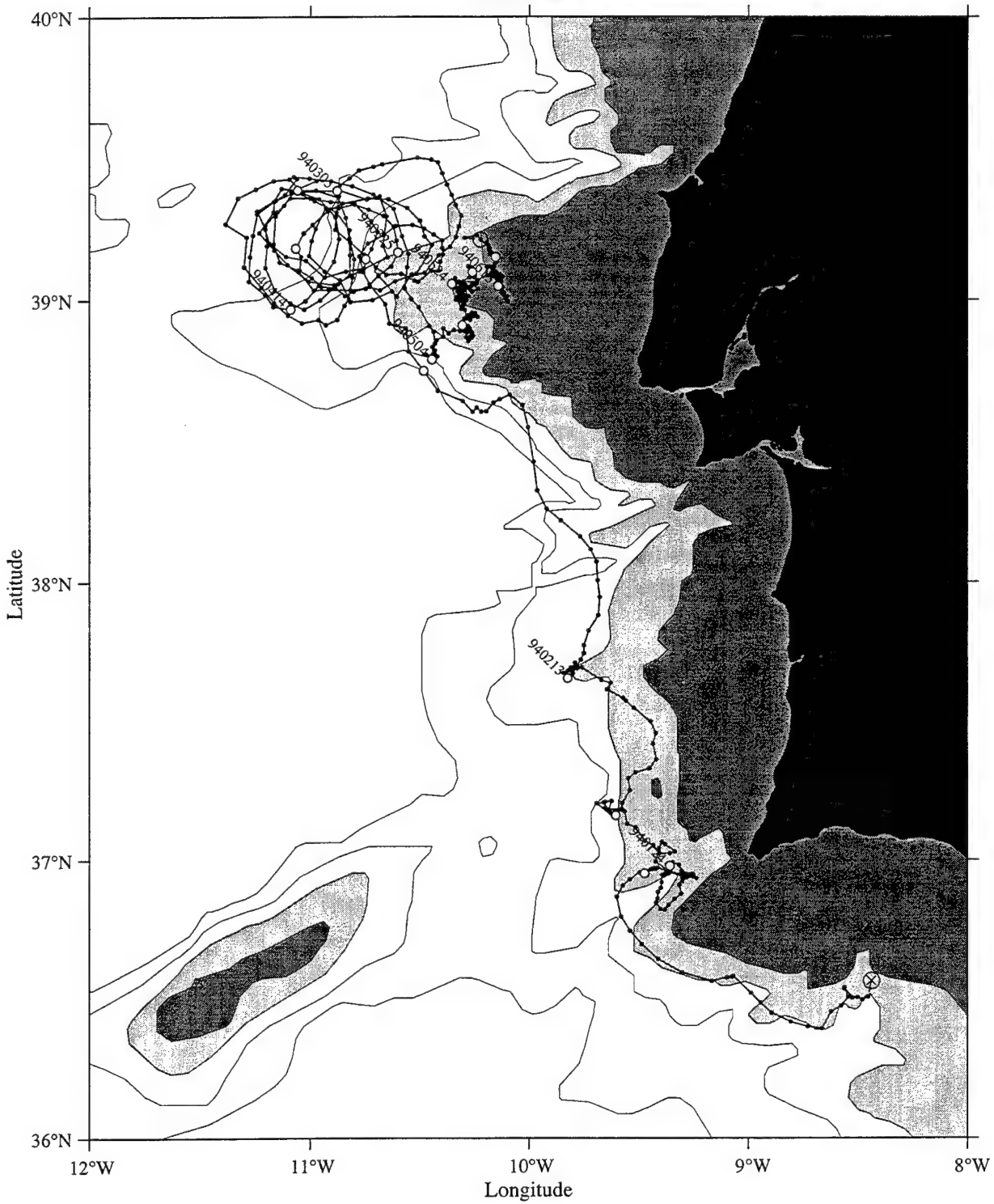


# am112

1994

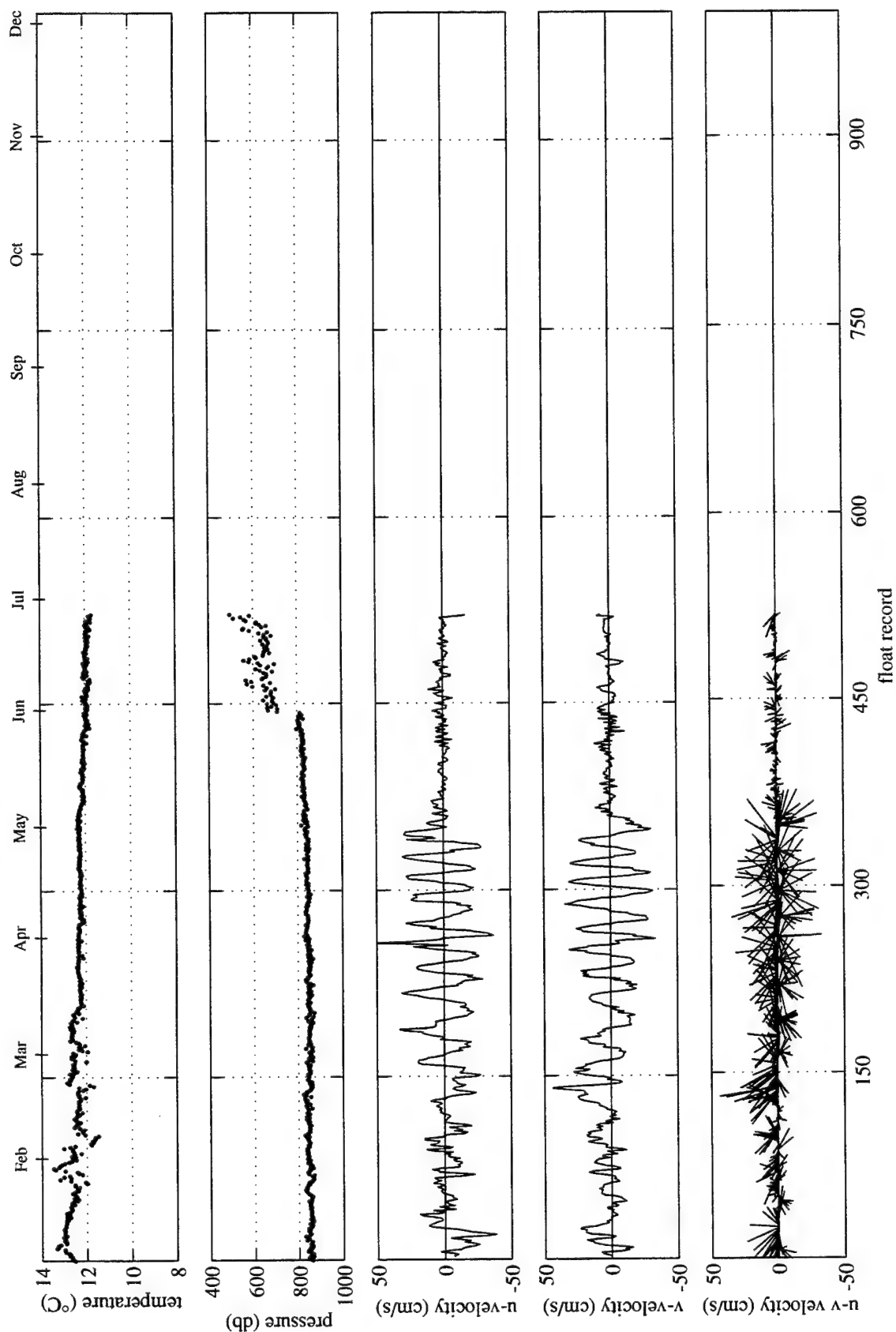


am114

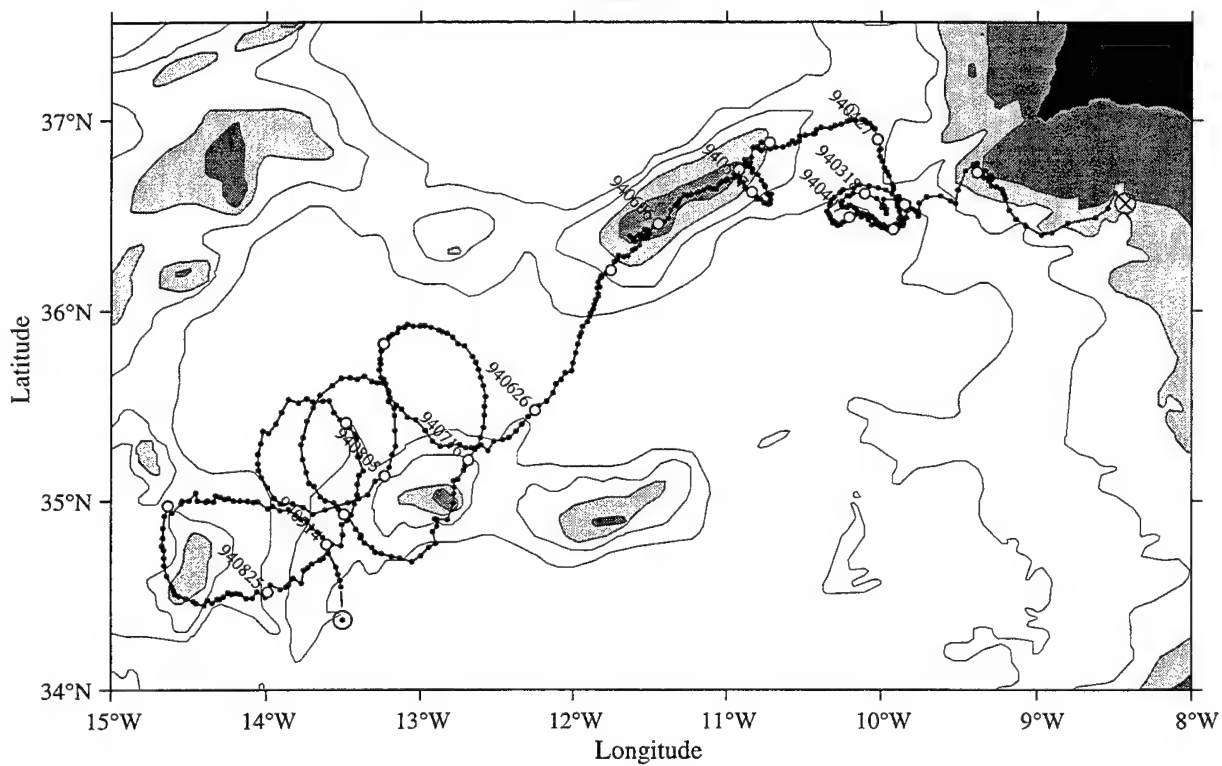


# am114

1994

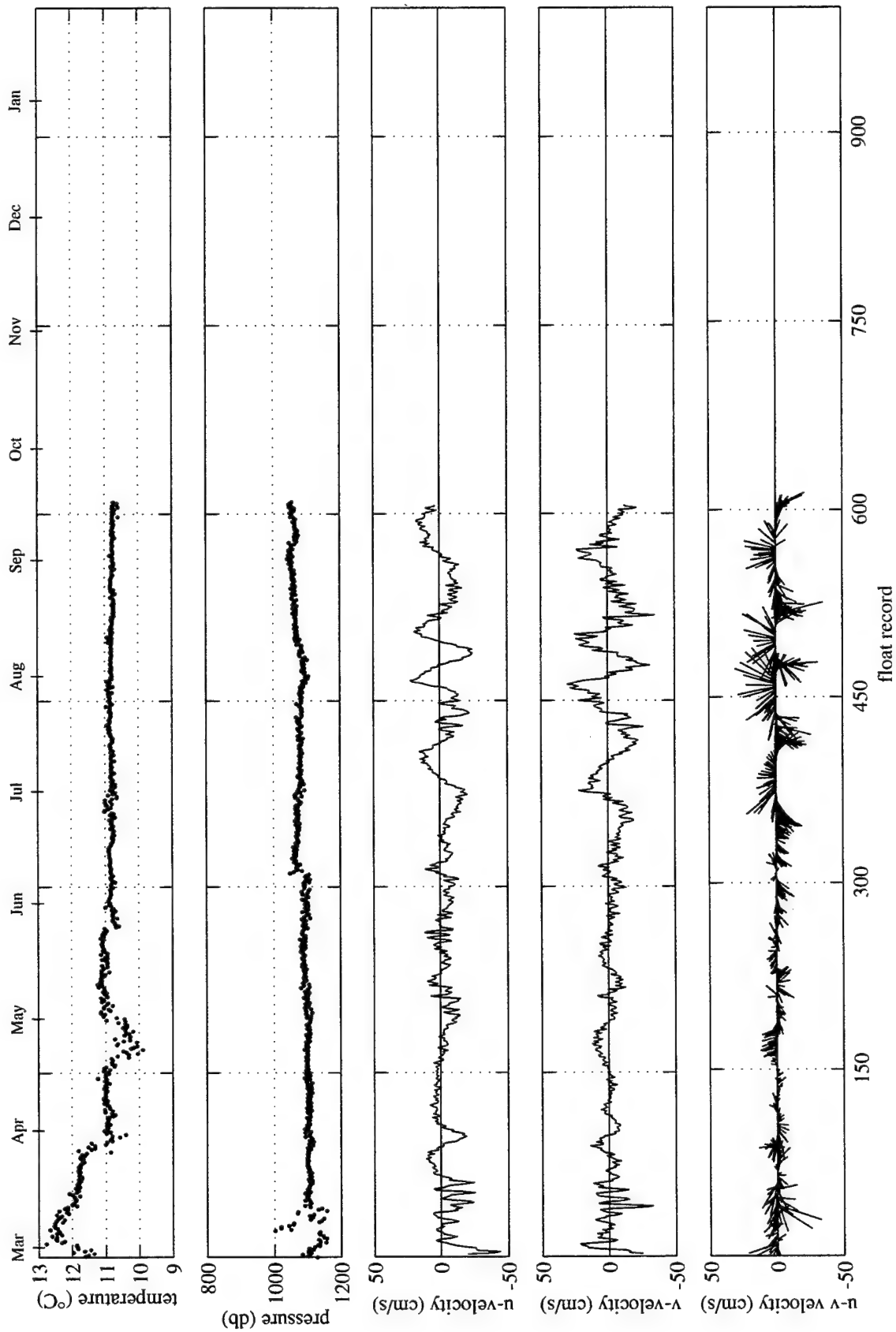


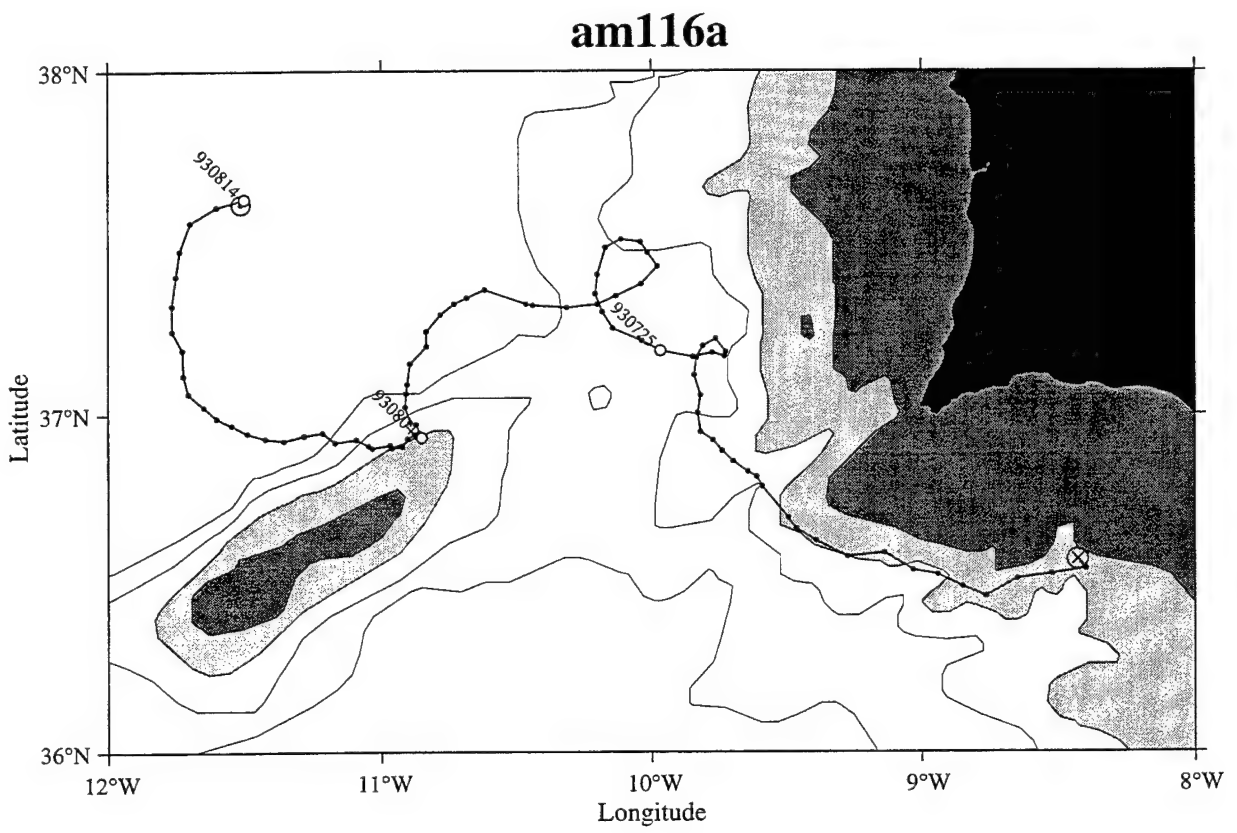
am115



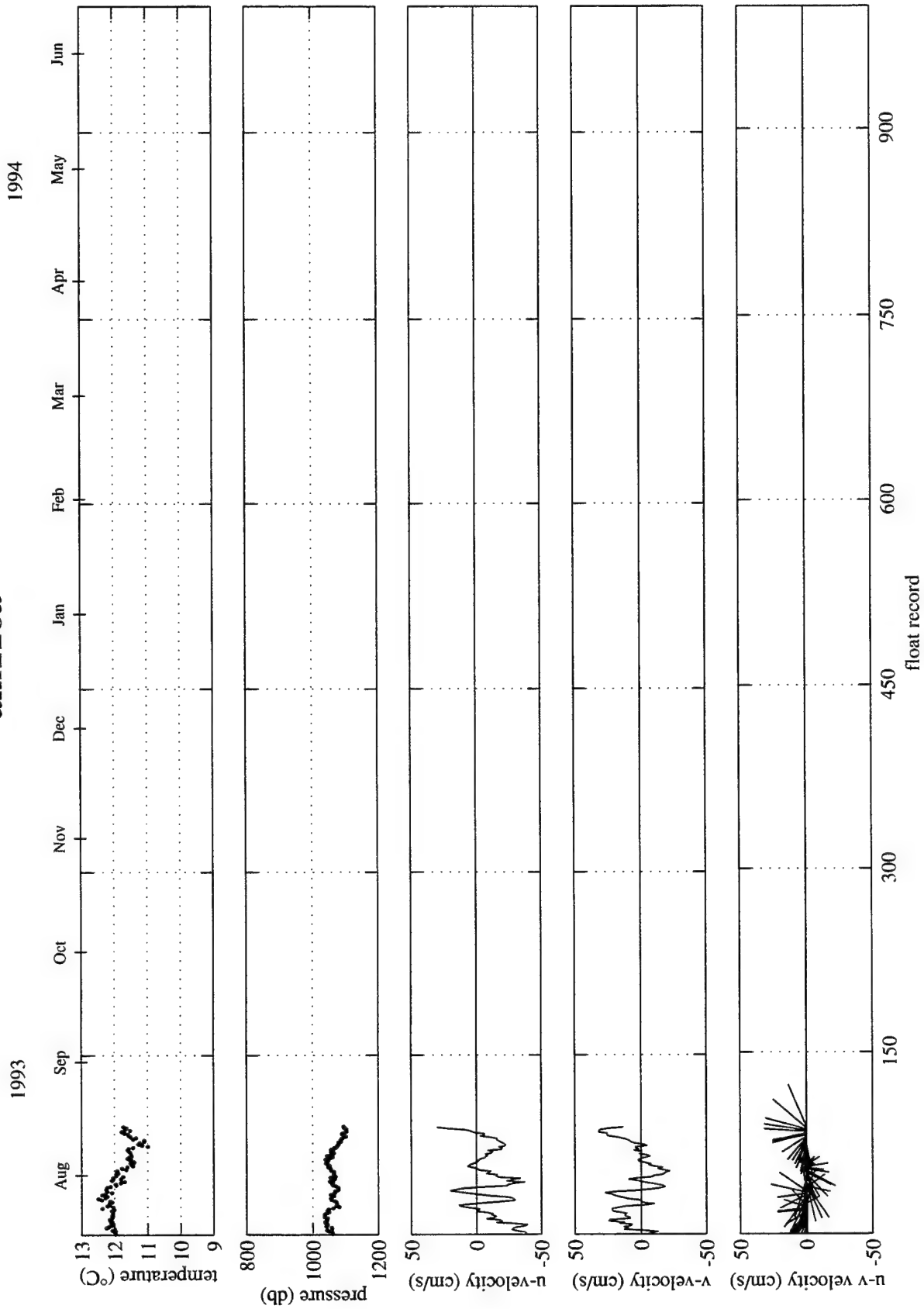
am115

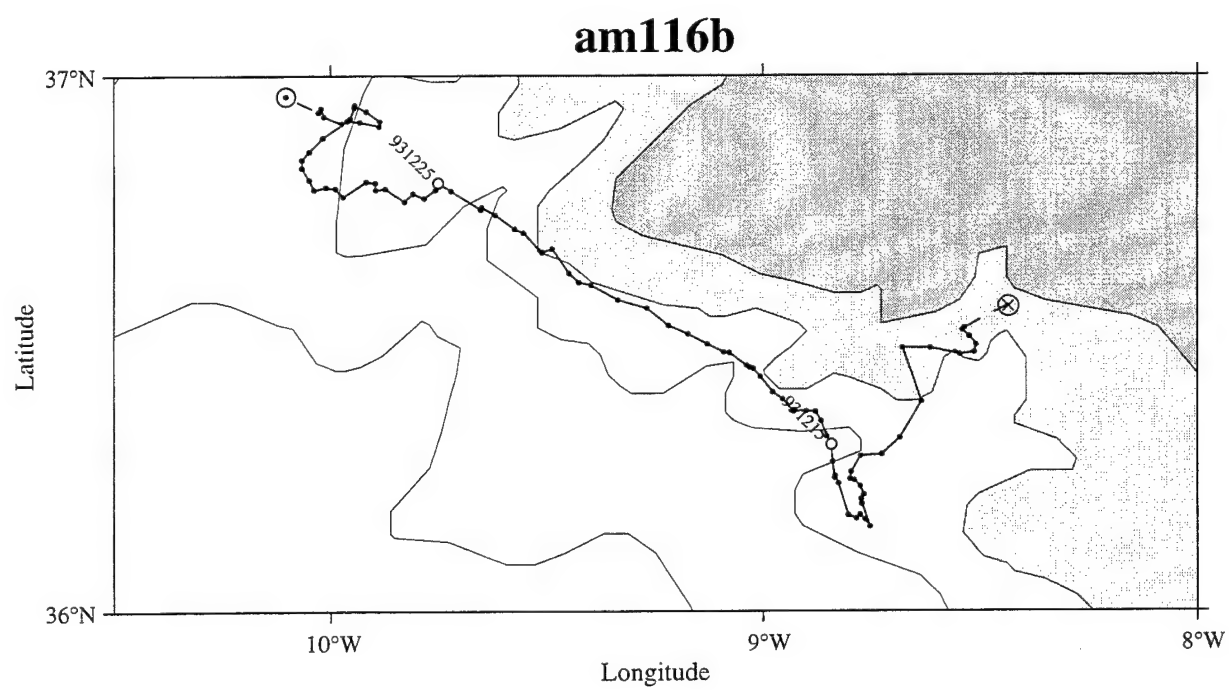
1994





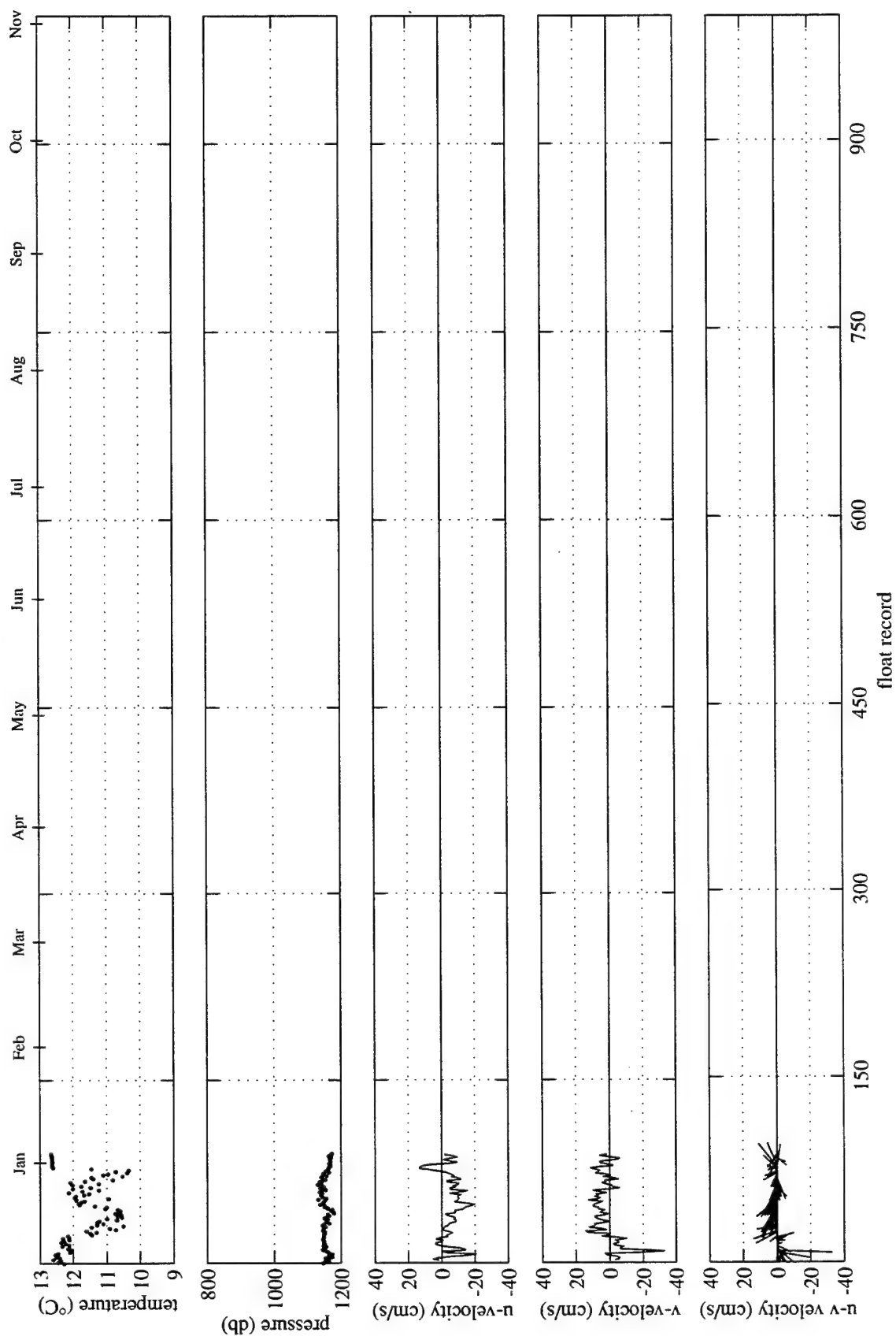
# am116a

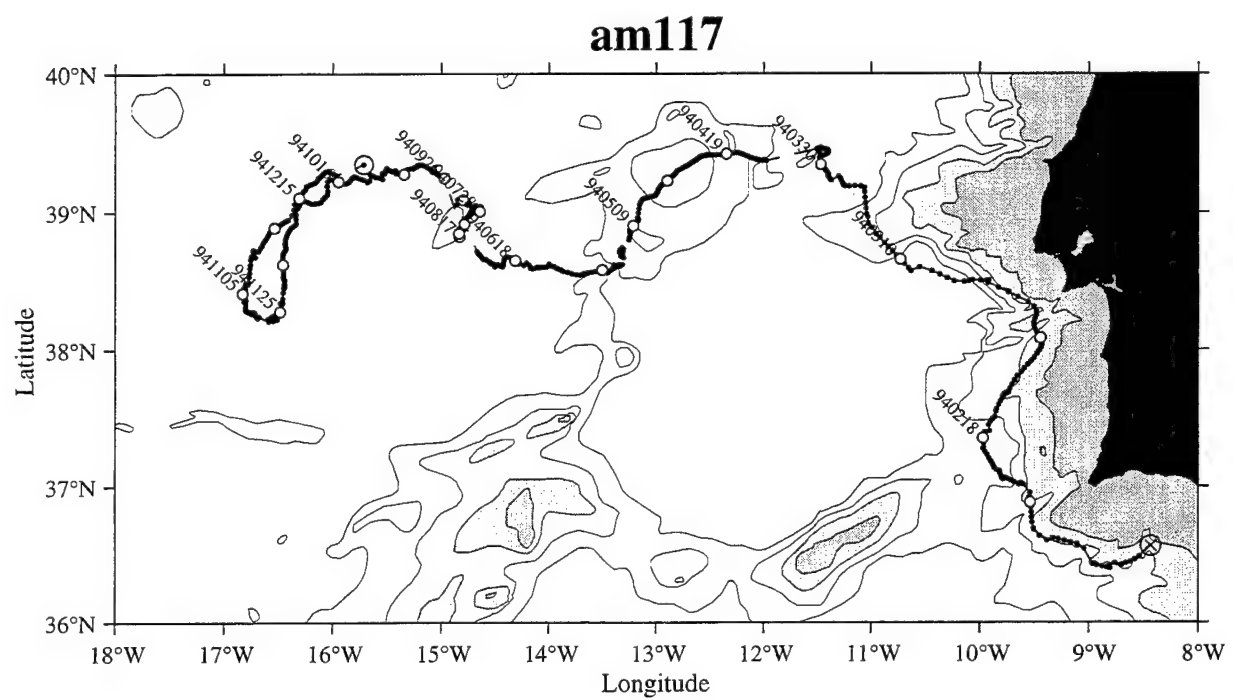






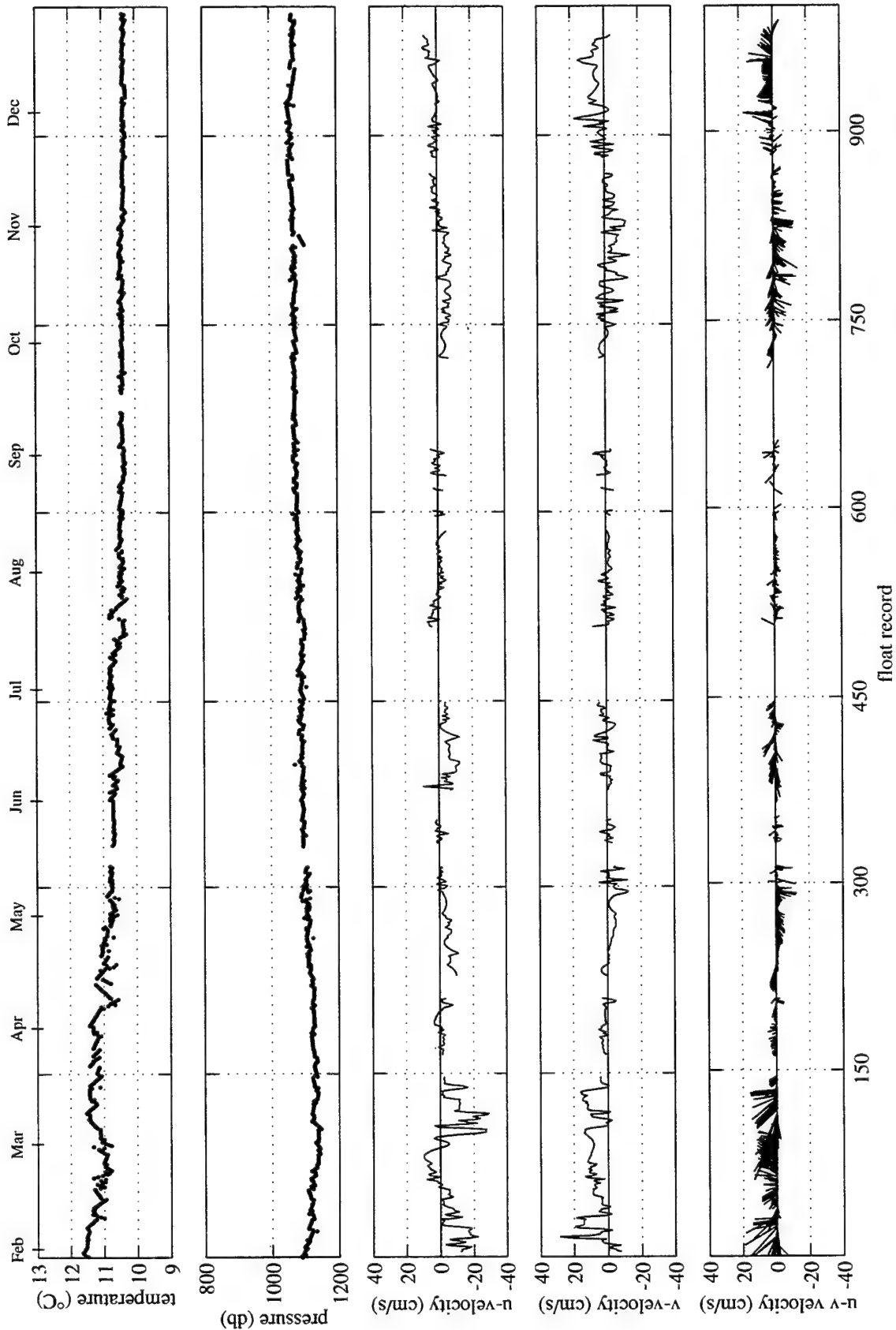
# am116b 1994



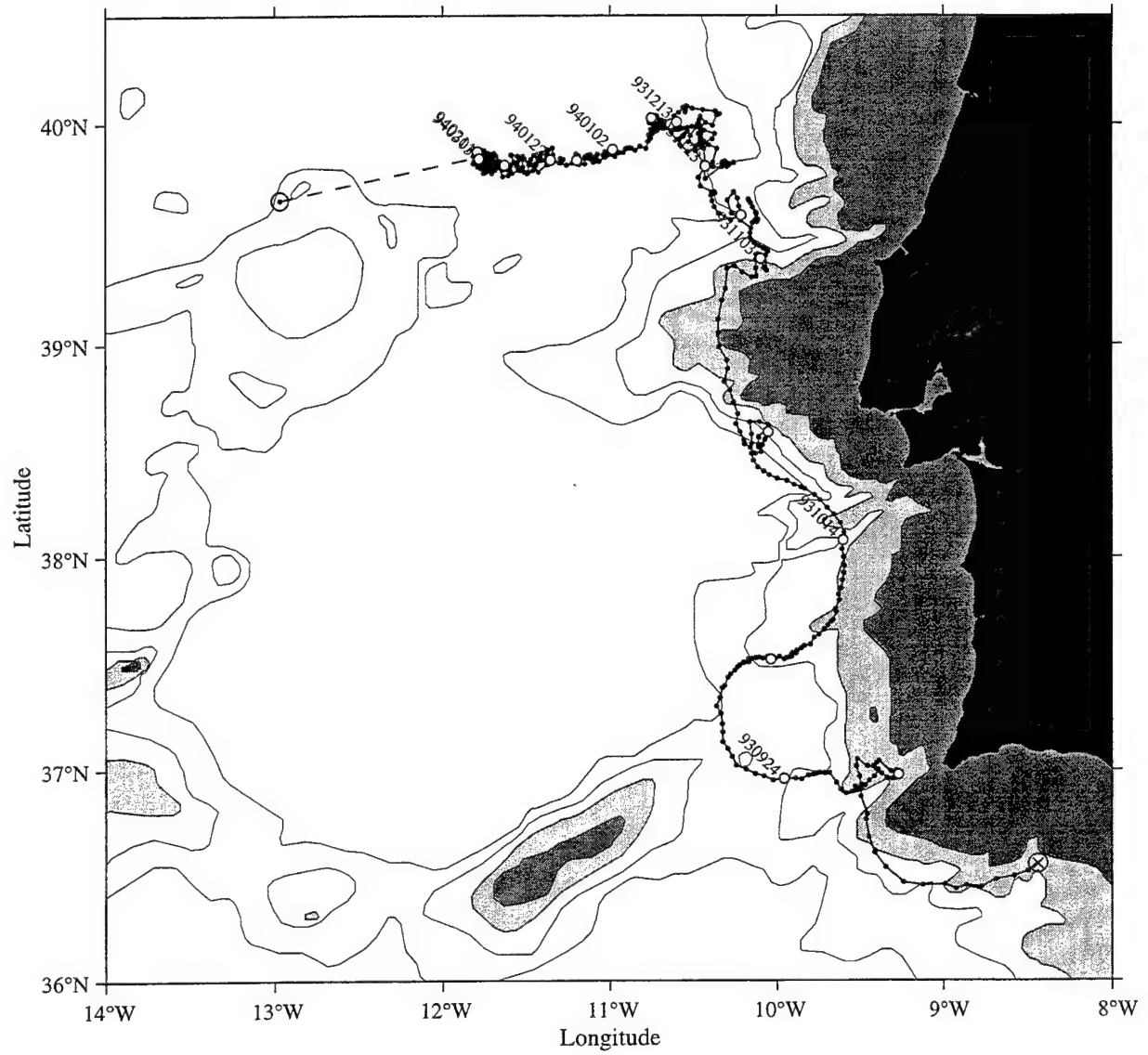


# am117

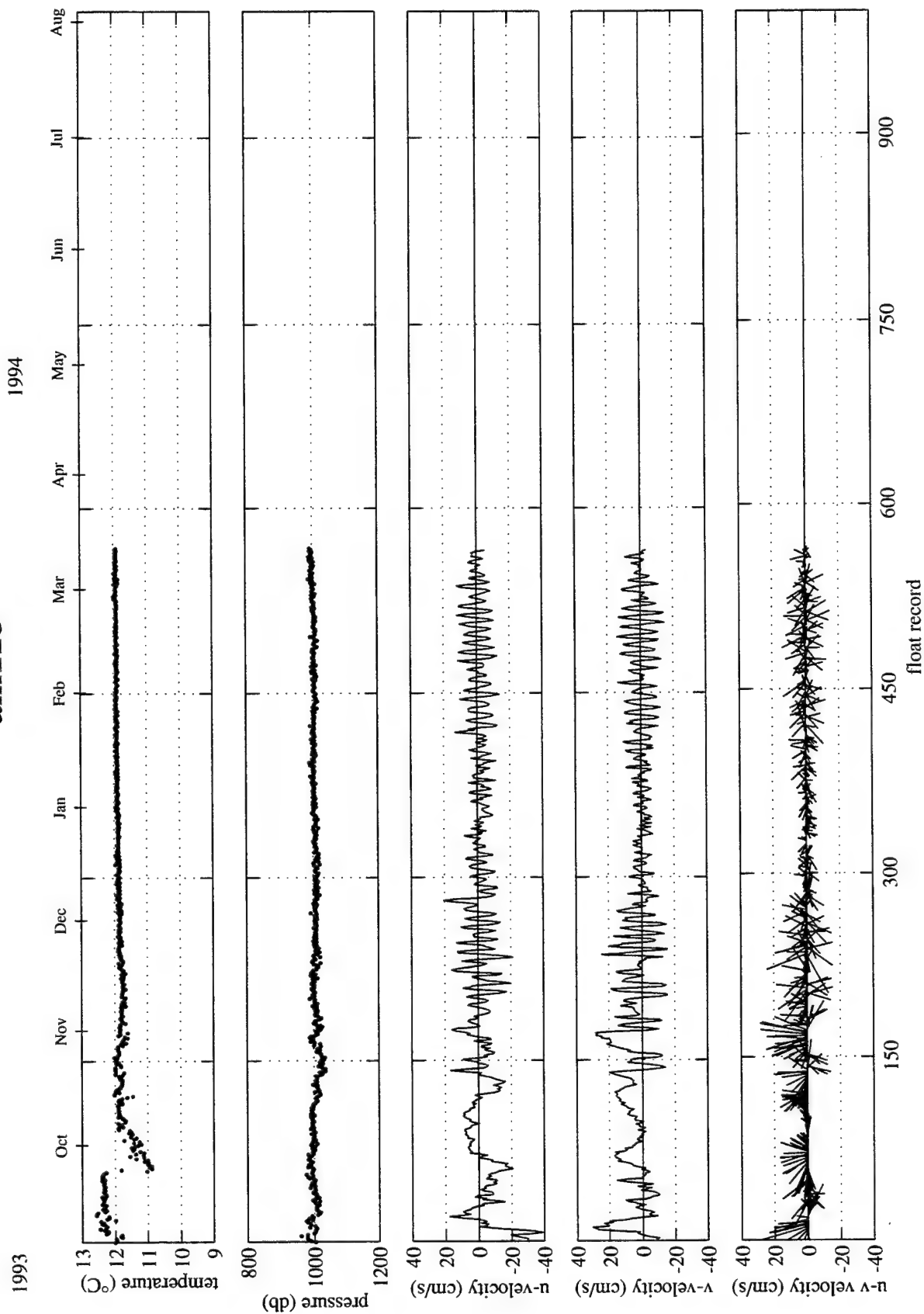
1994



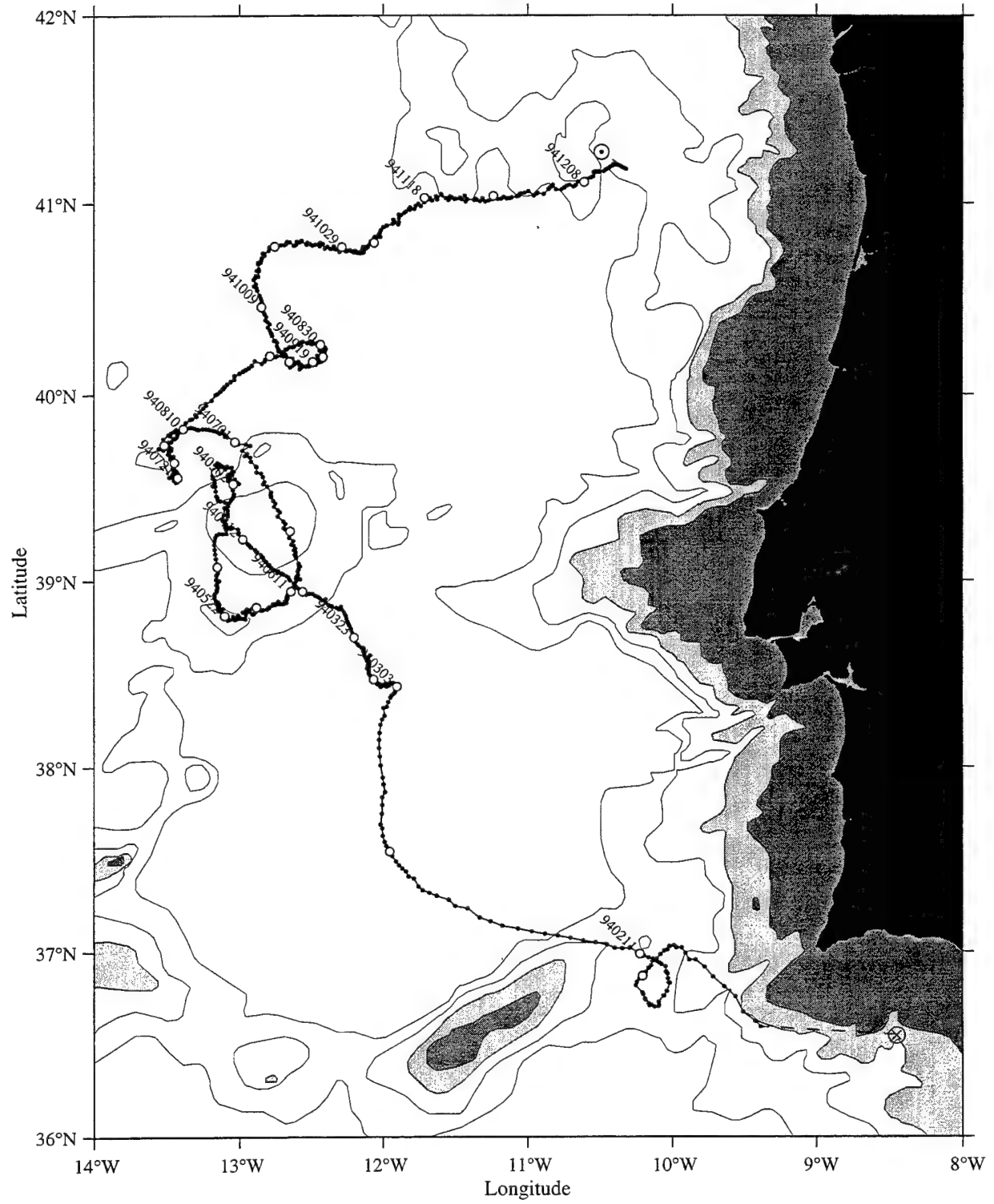
am118



# am118

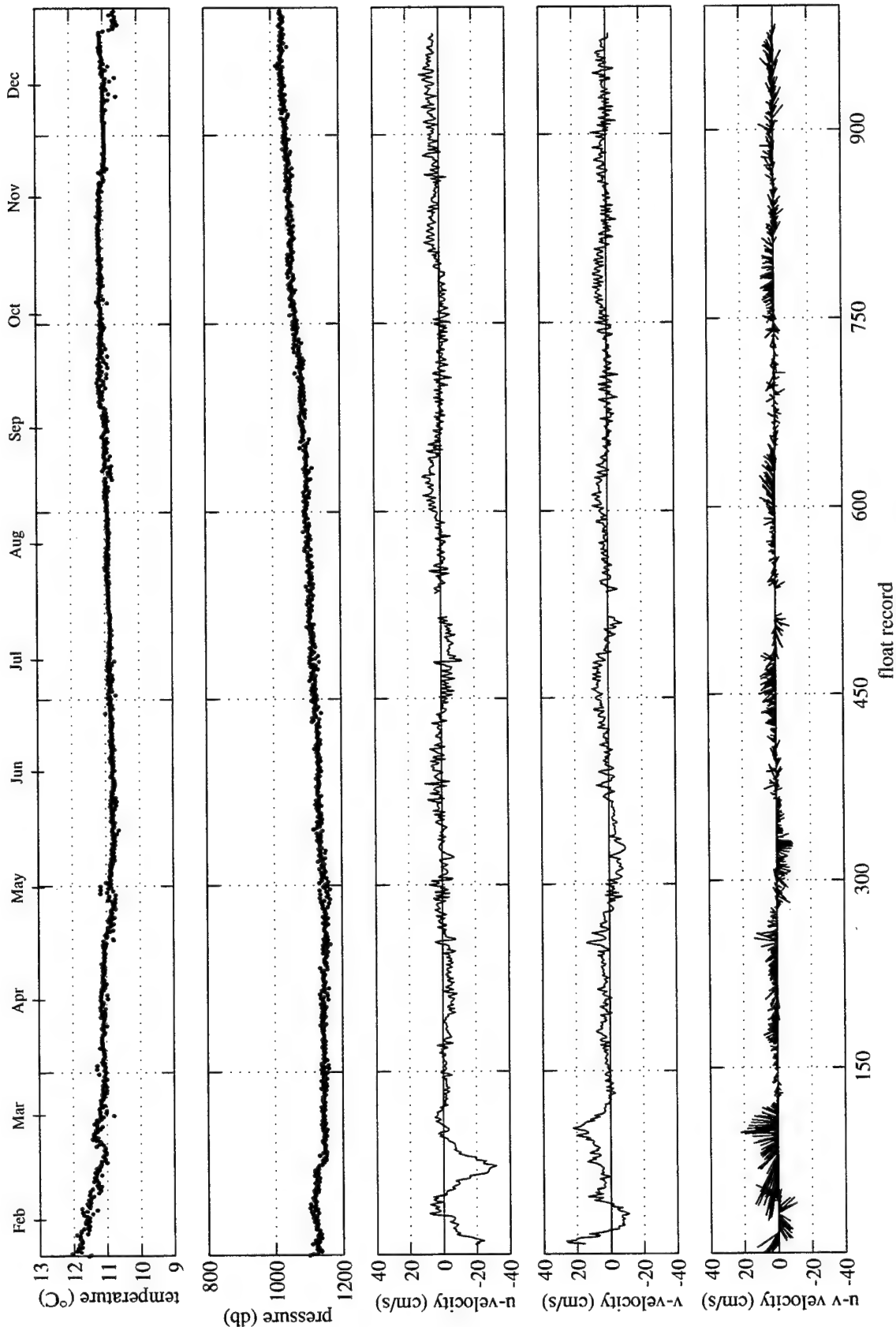


am119

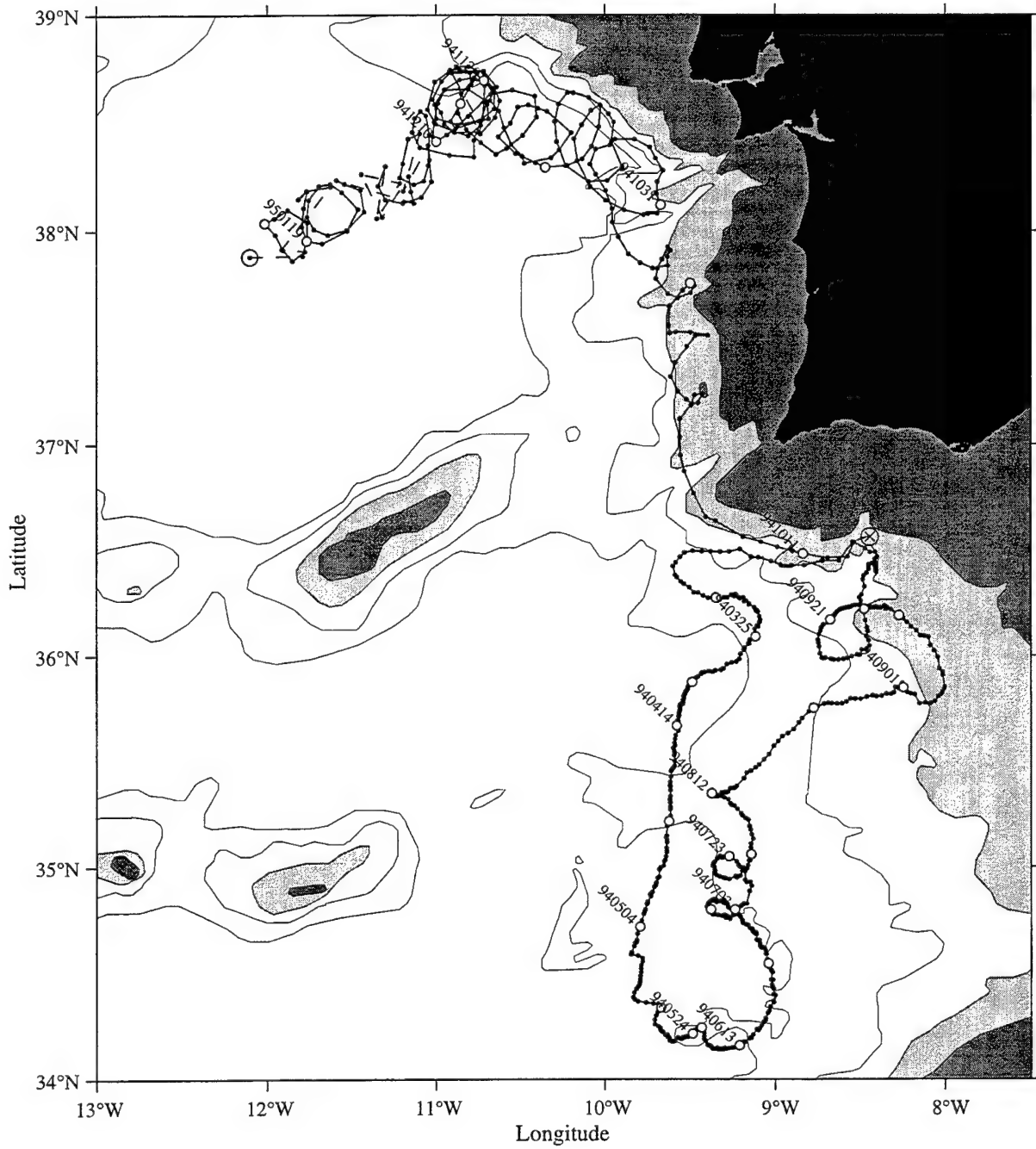


# am119

1994

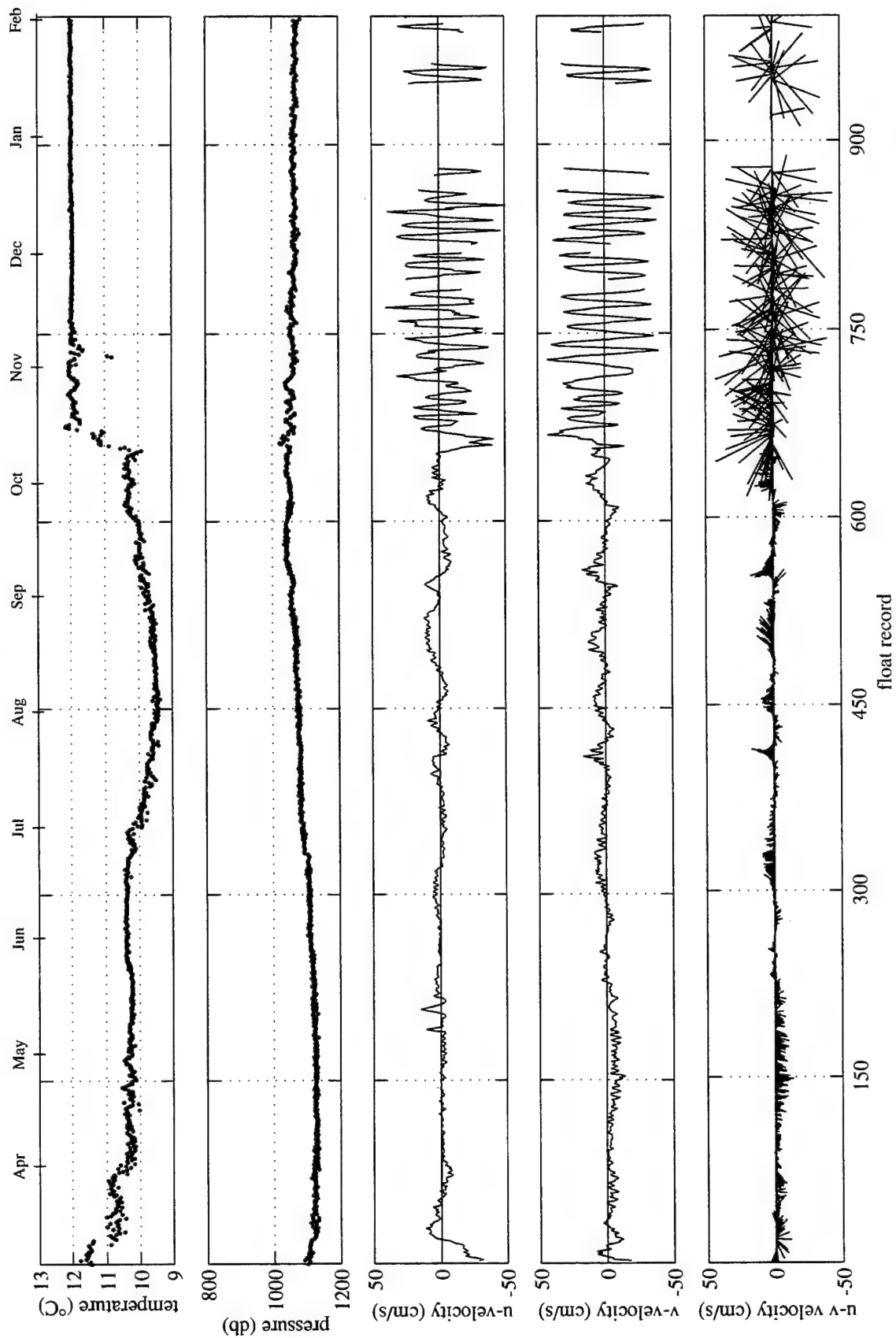


am120b

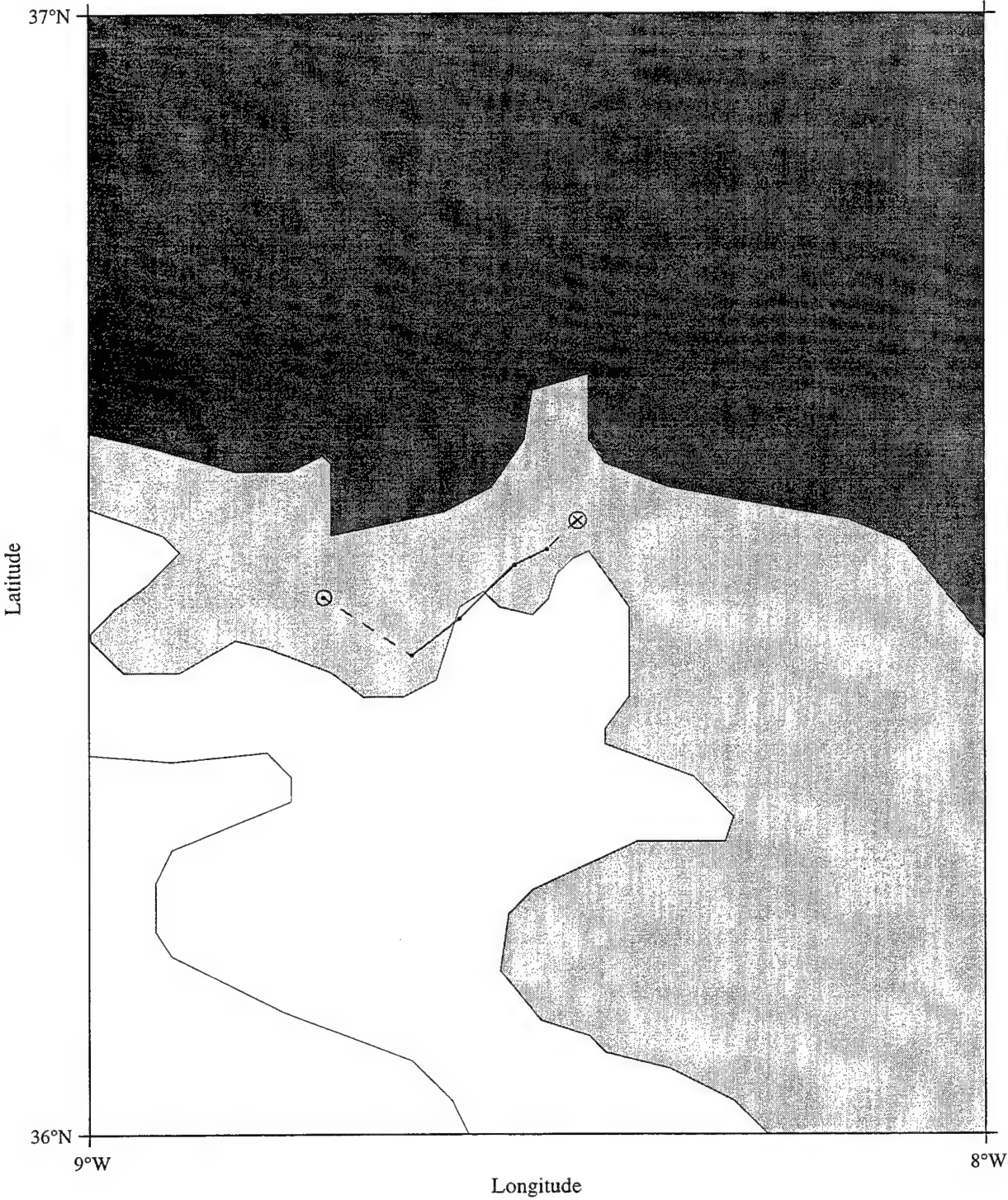




# am120b 1994

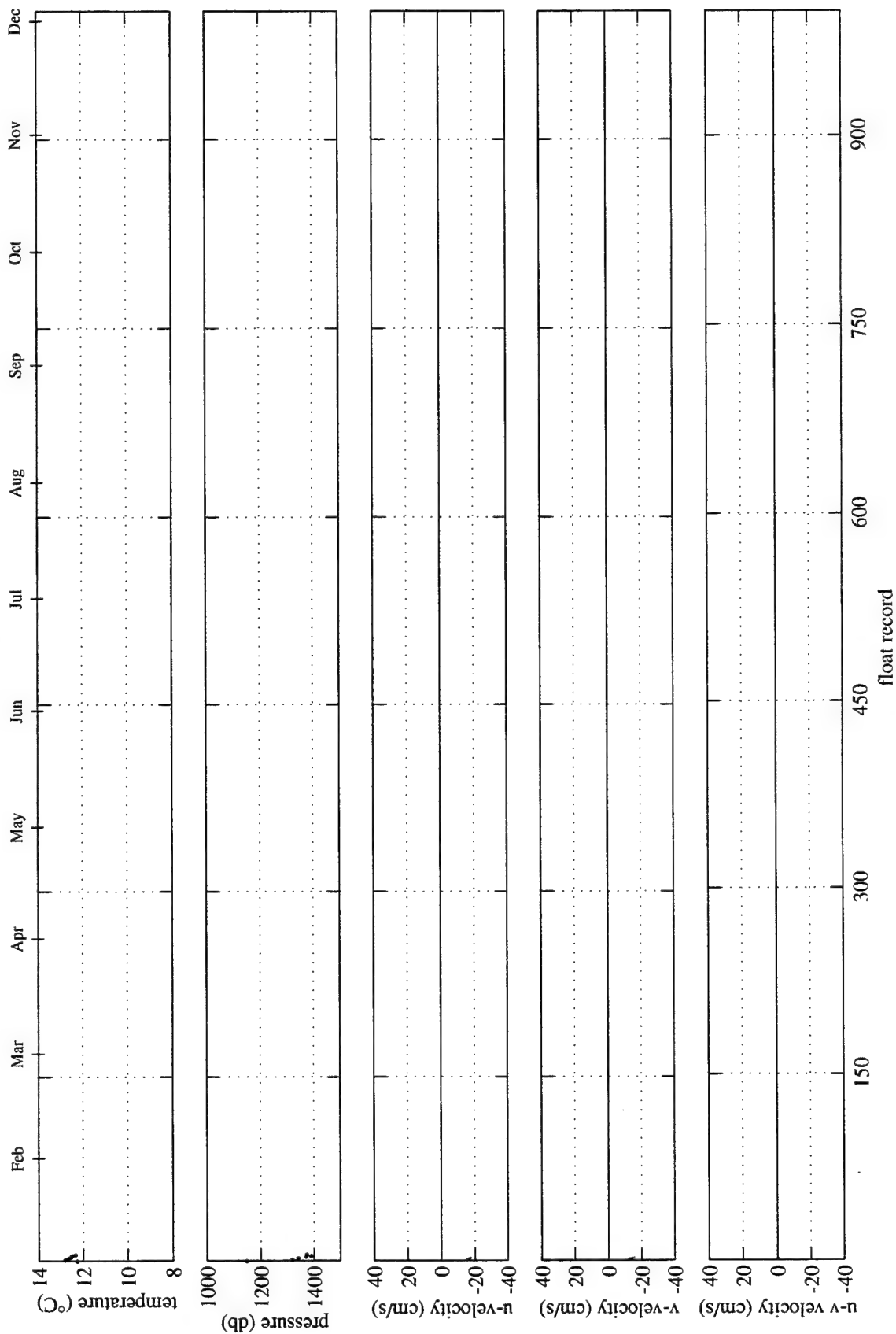


am121a

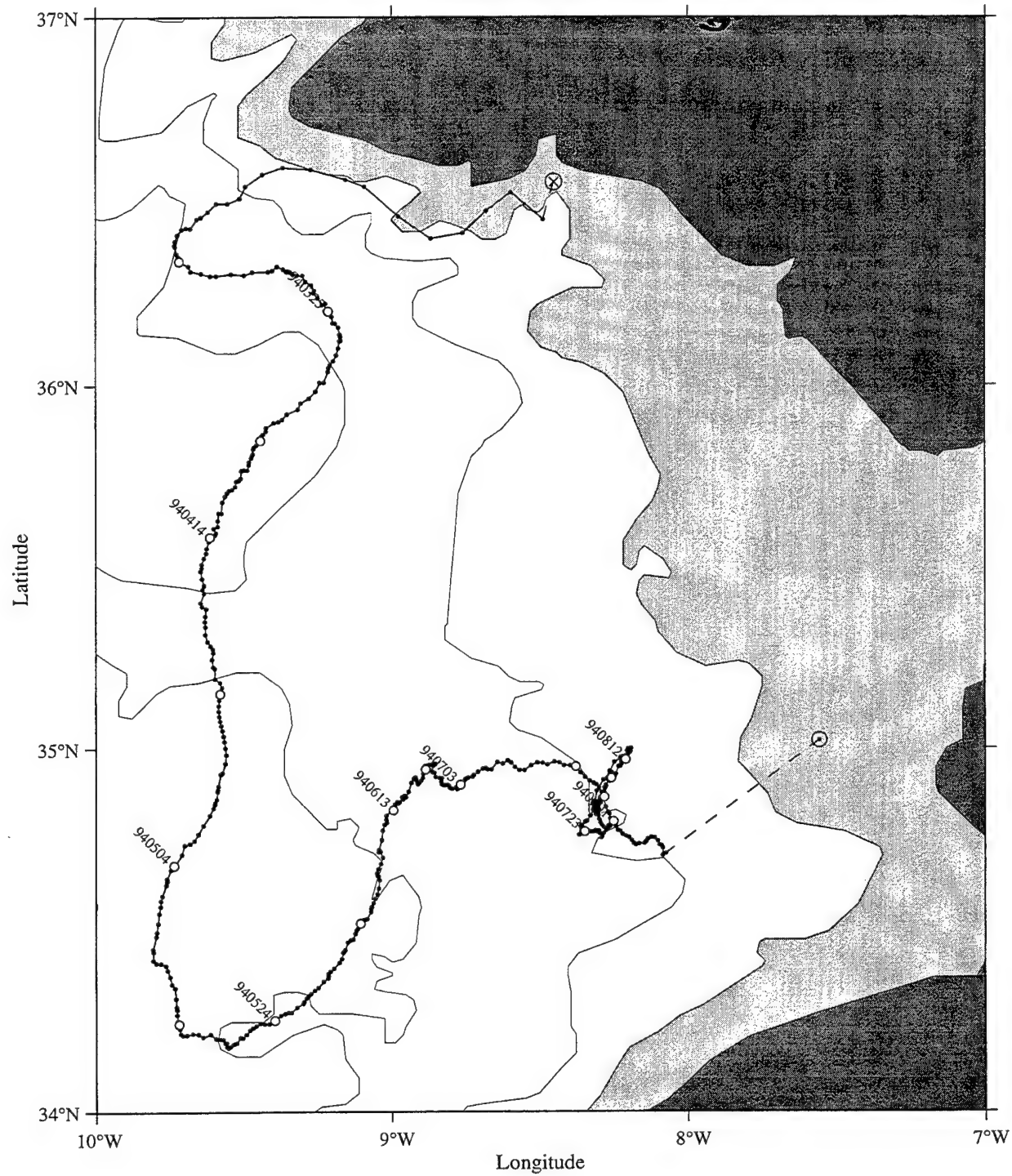


# am121a

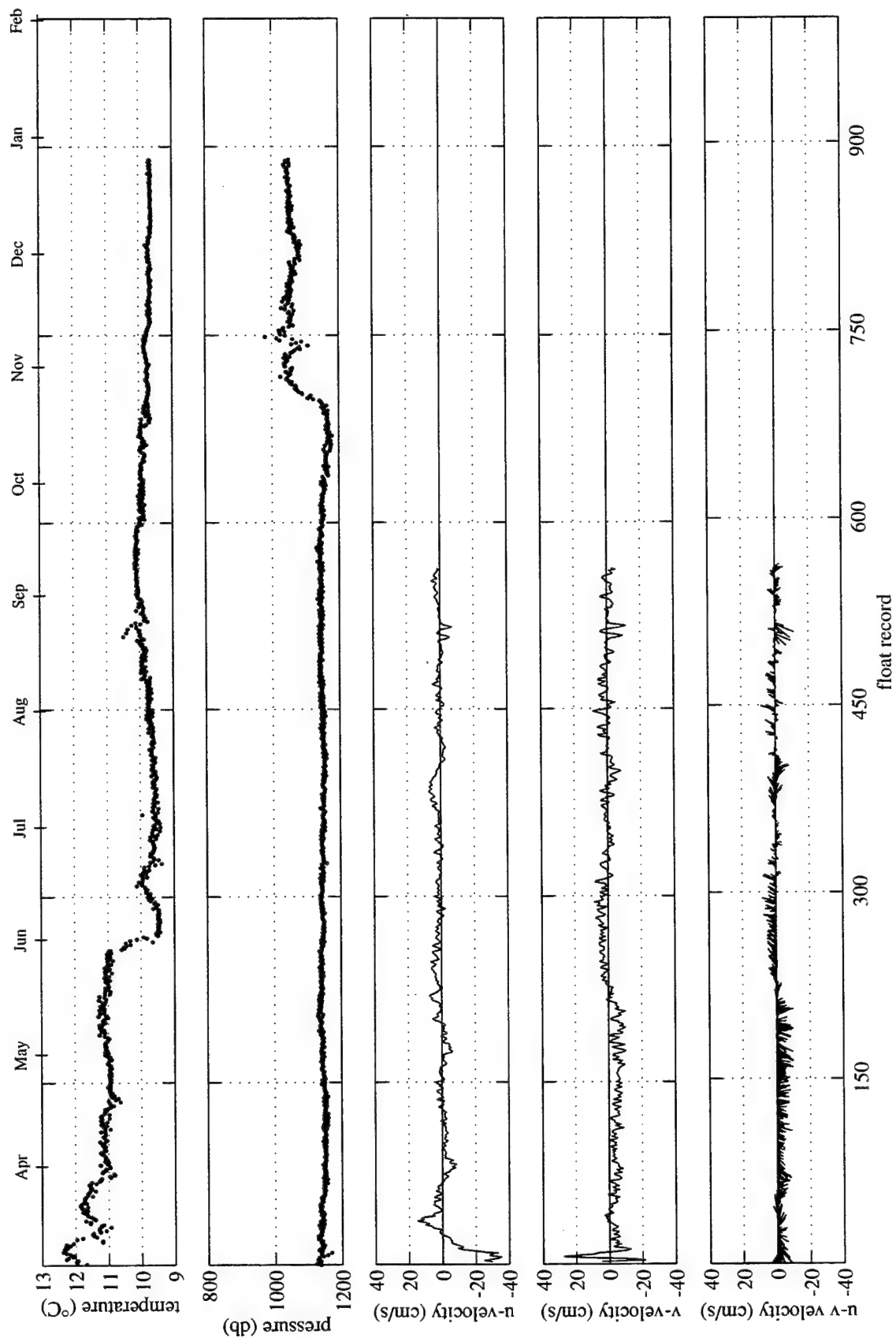
1994



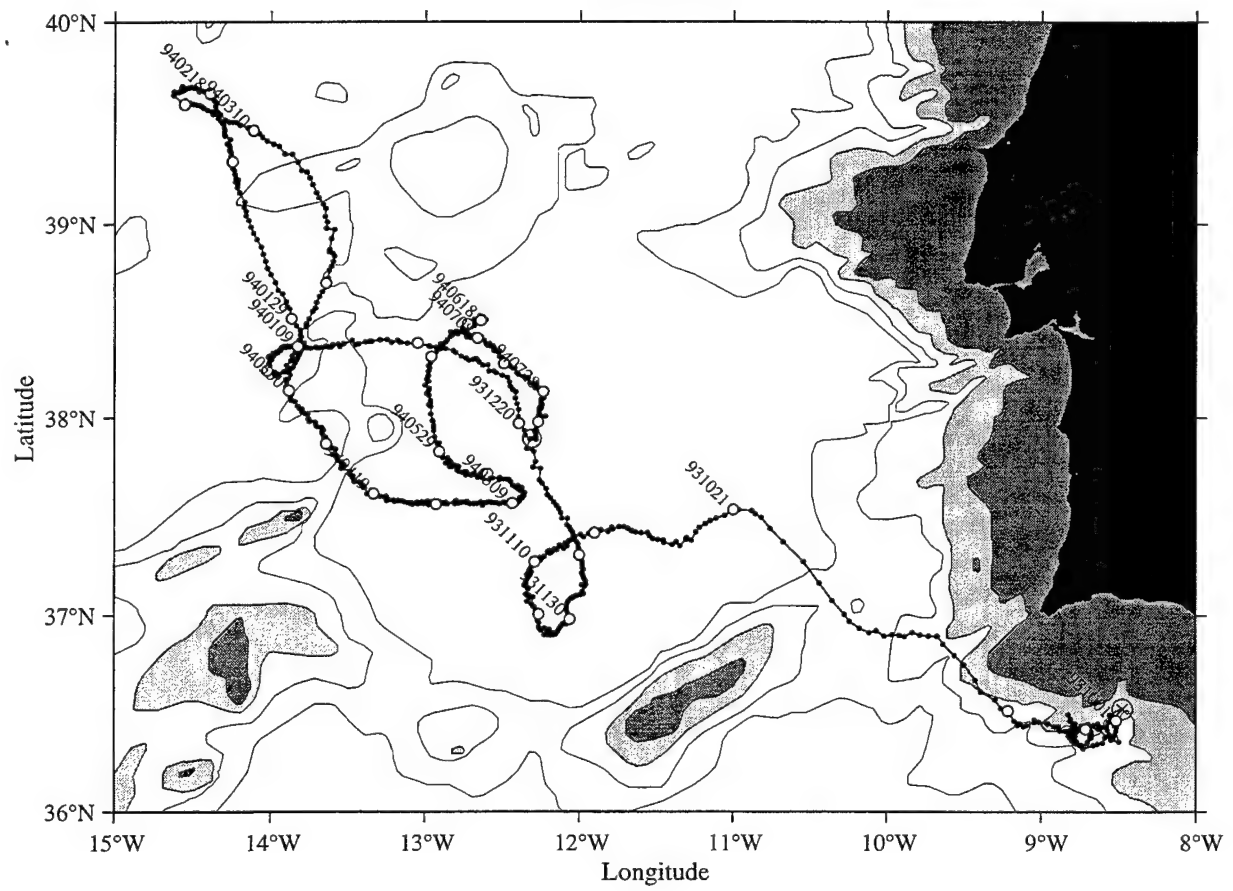
# am121b



# am121b 1994



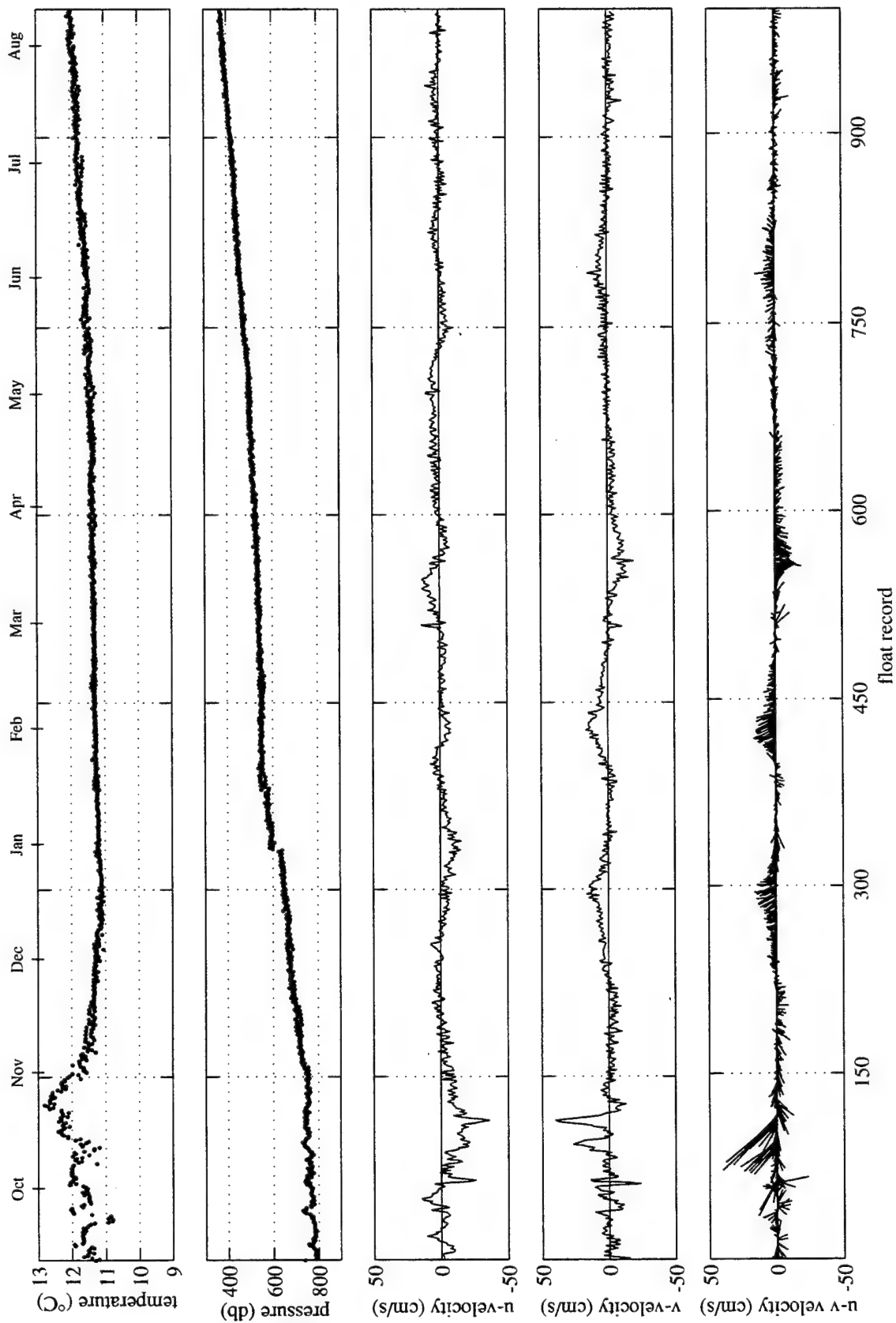
am122



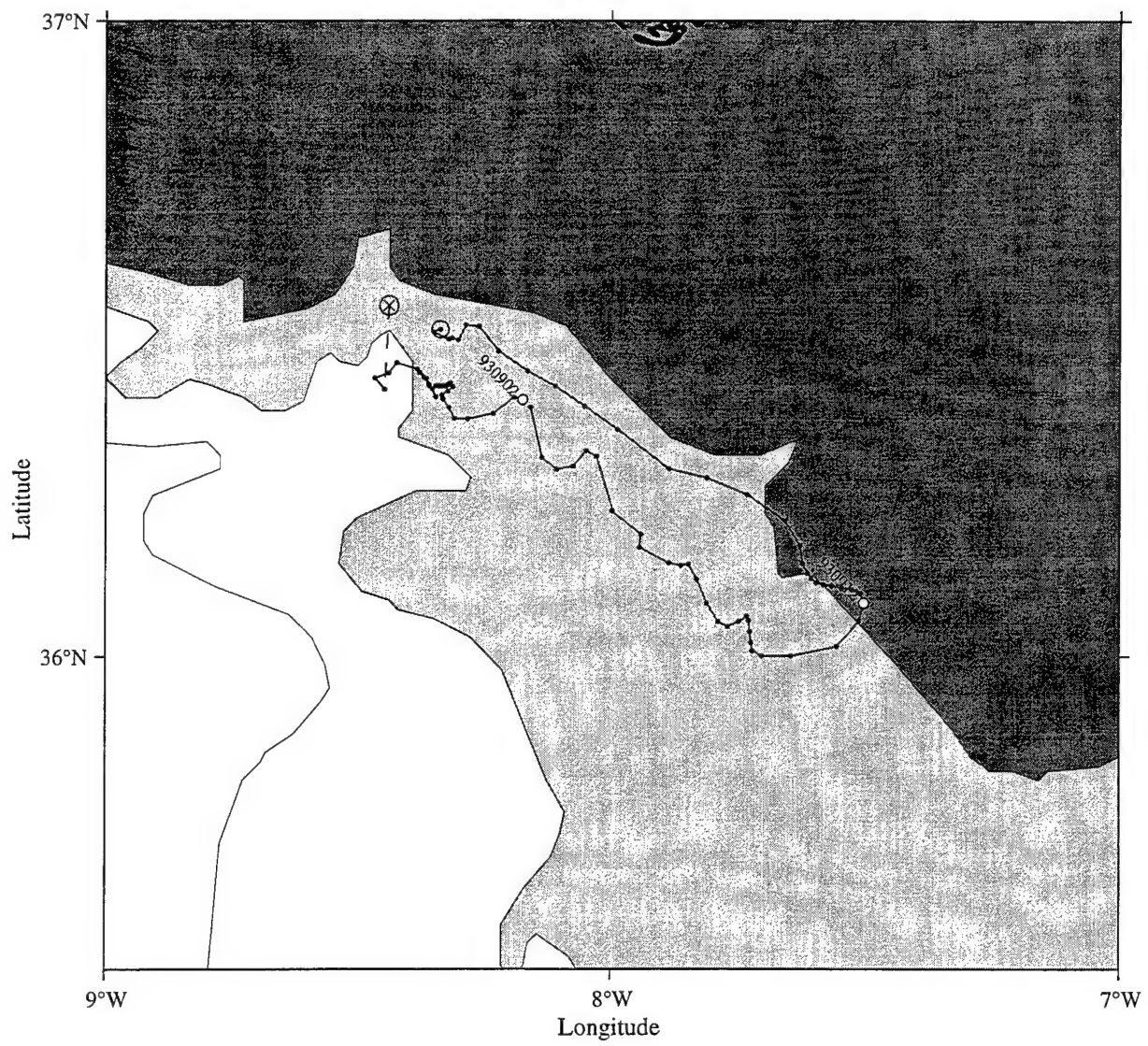
# am122

1993

1994

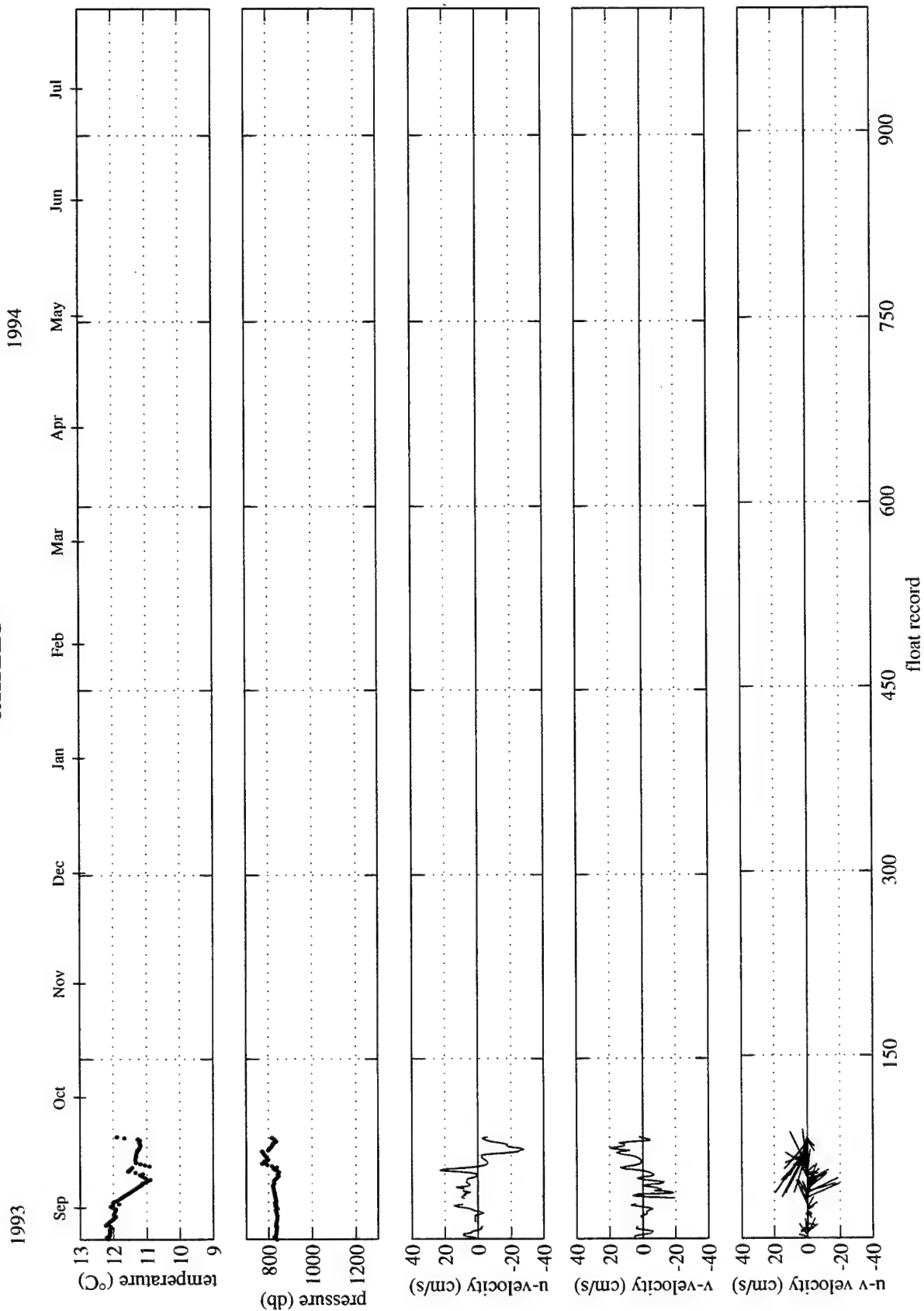


am123

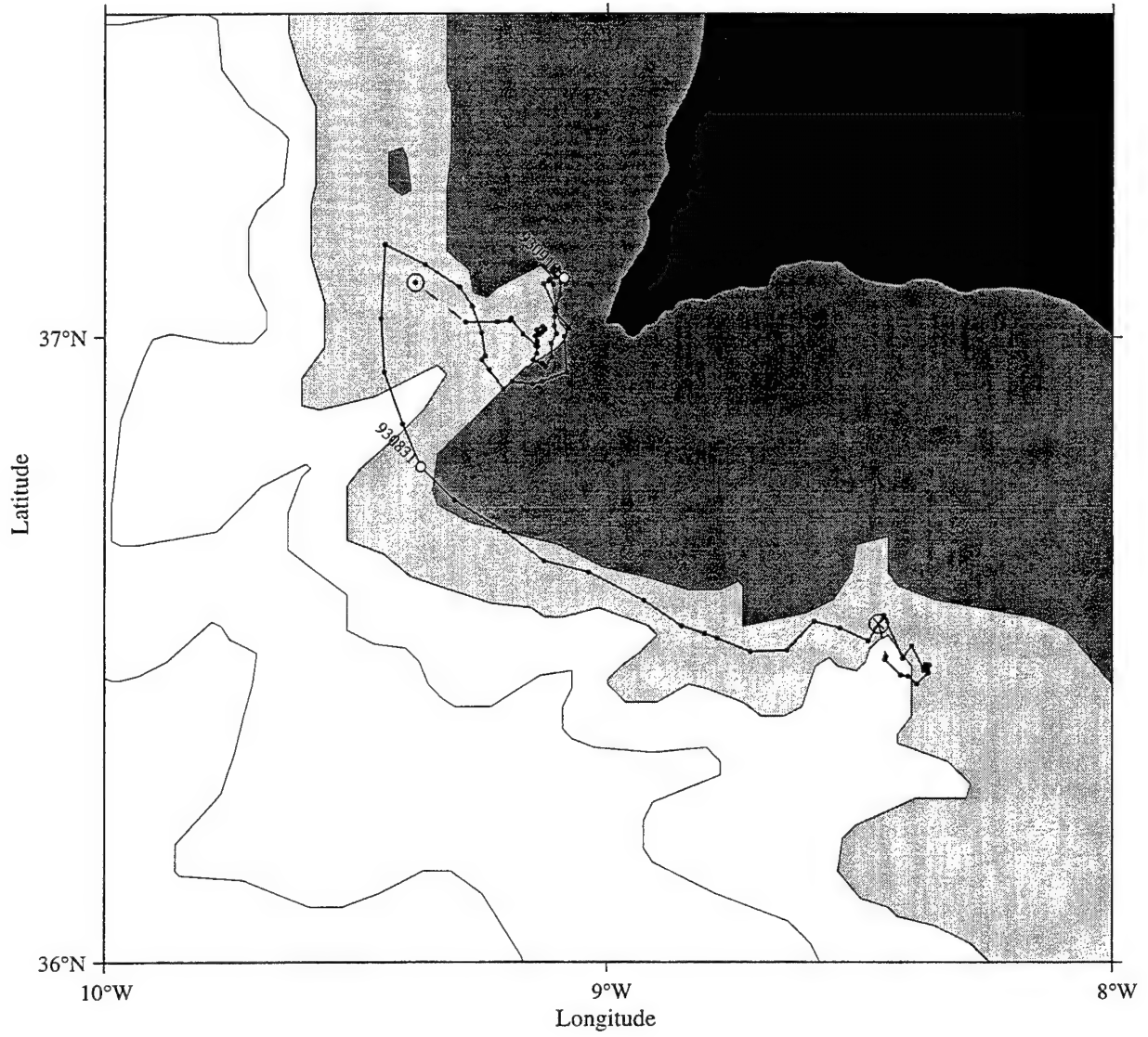




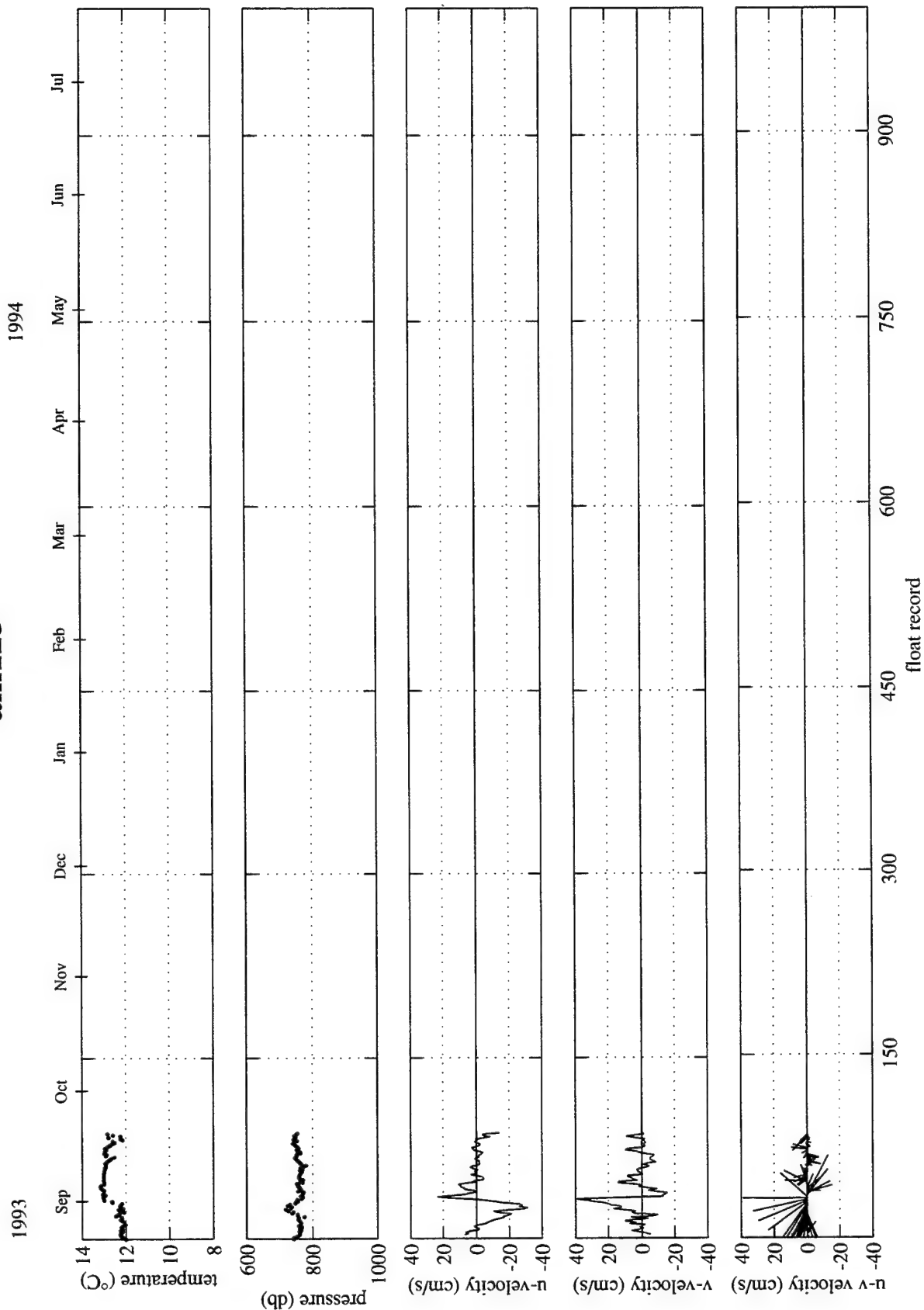
# am123



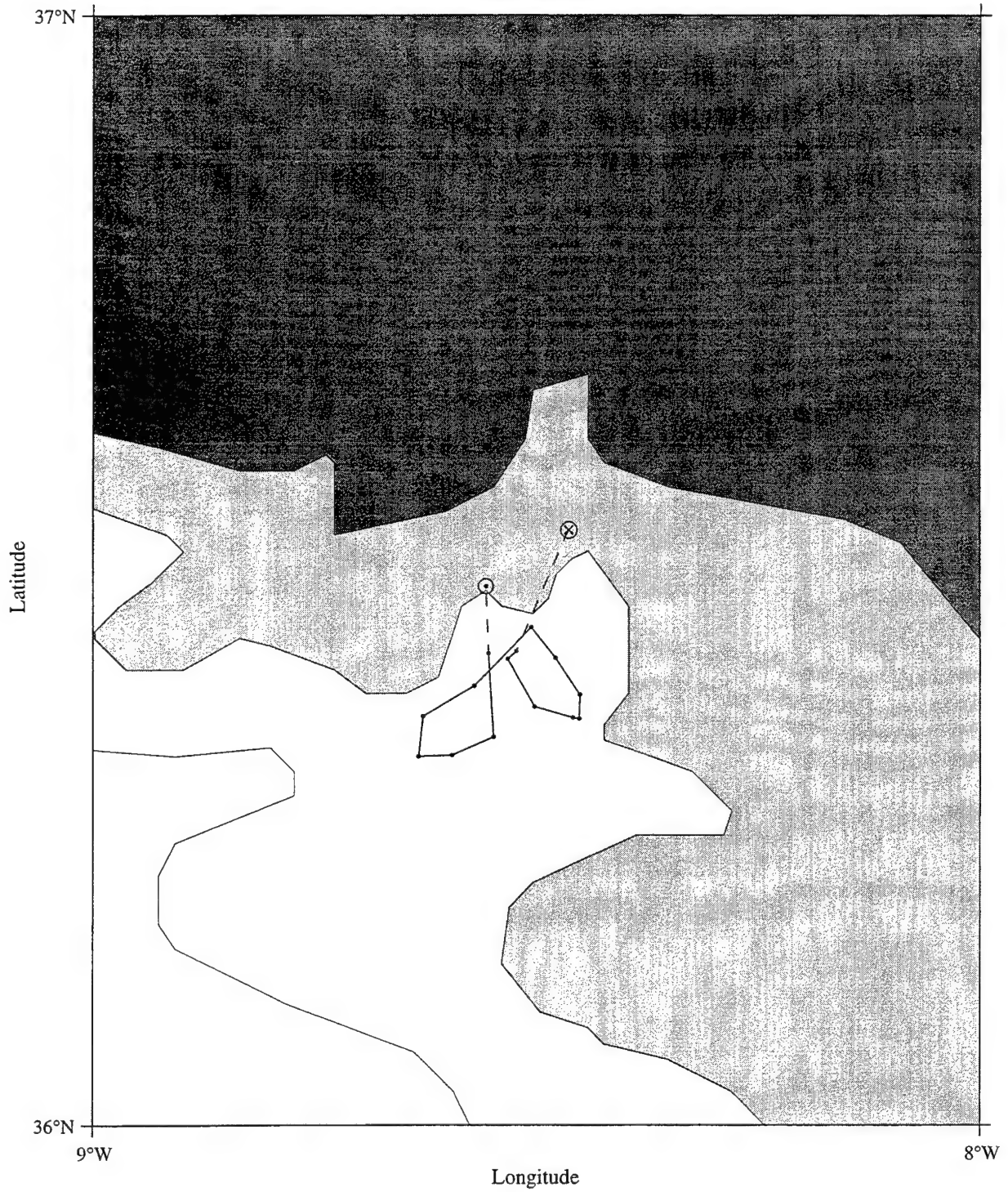
am125



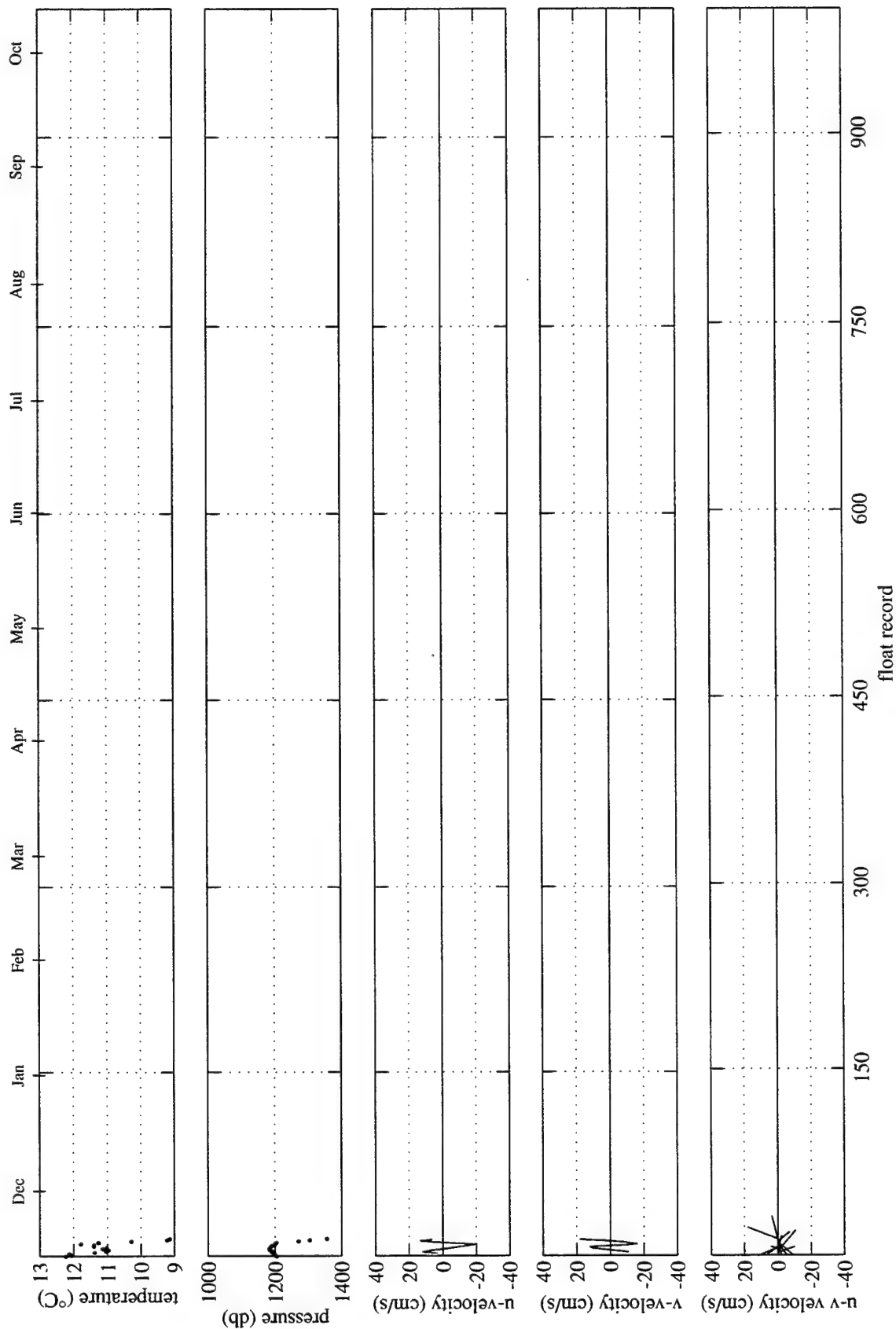
# am125



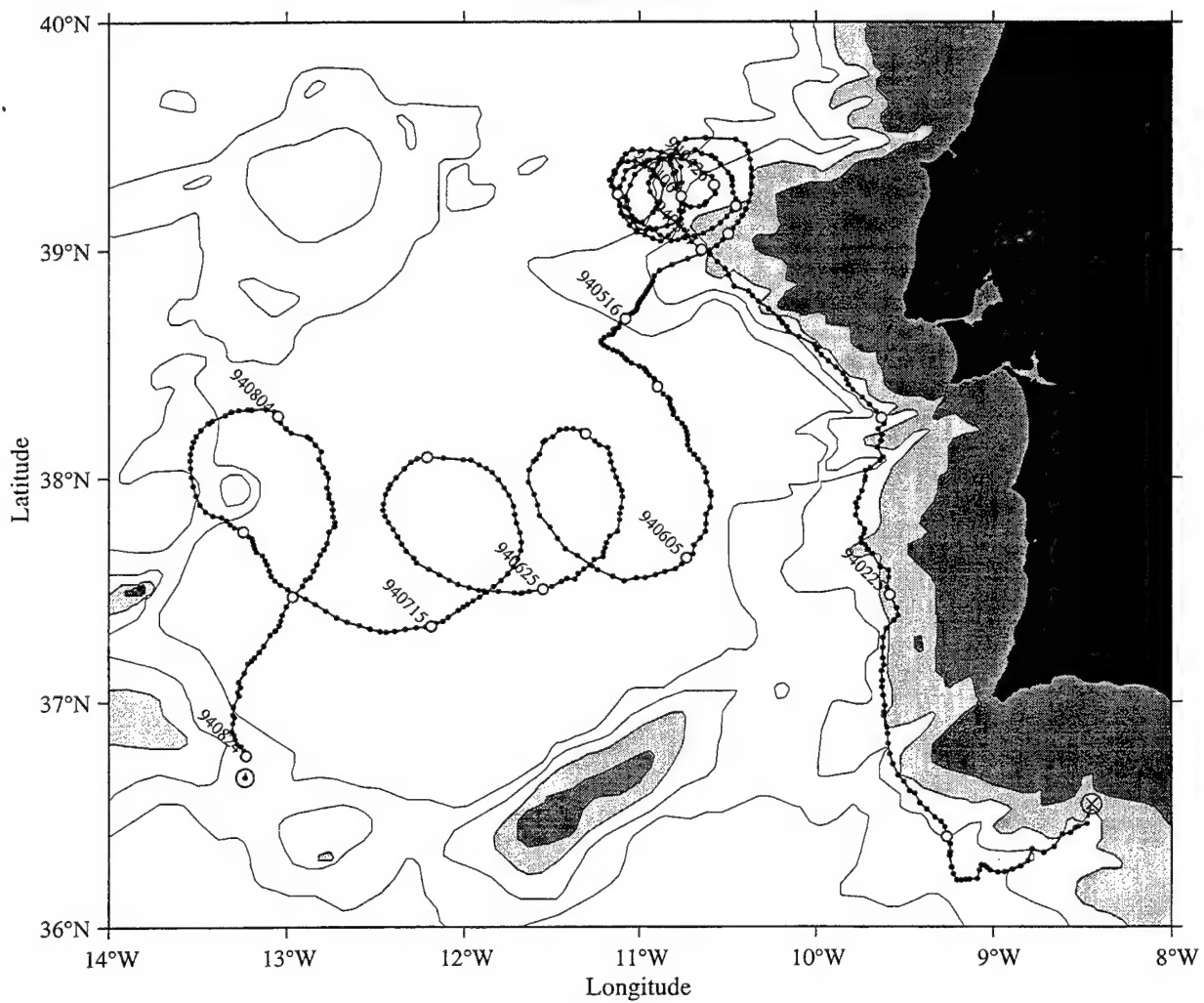
am126a



# am126a 1994

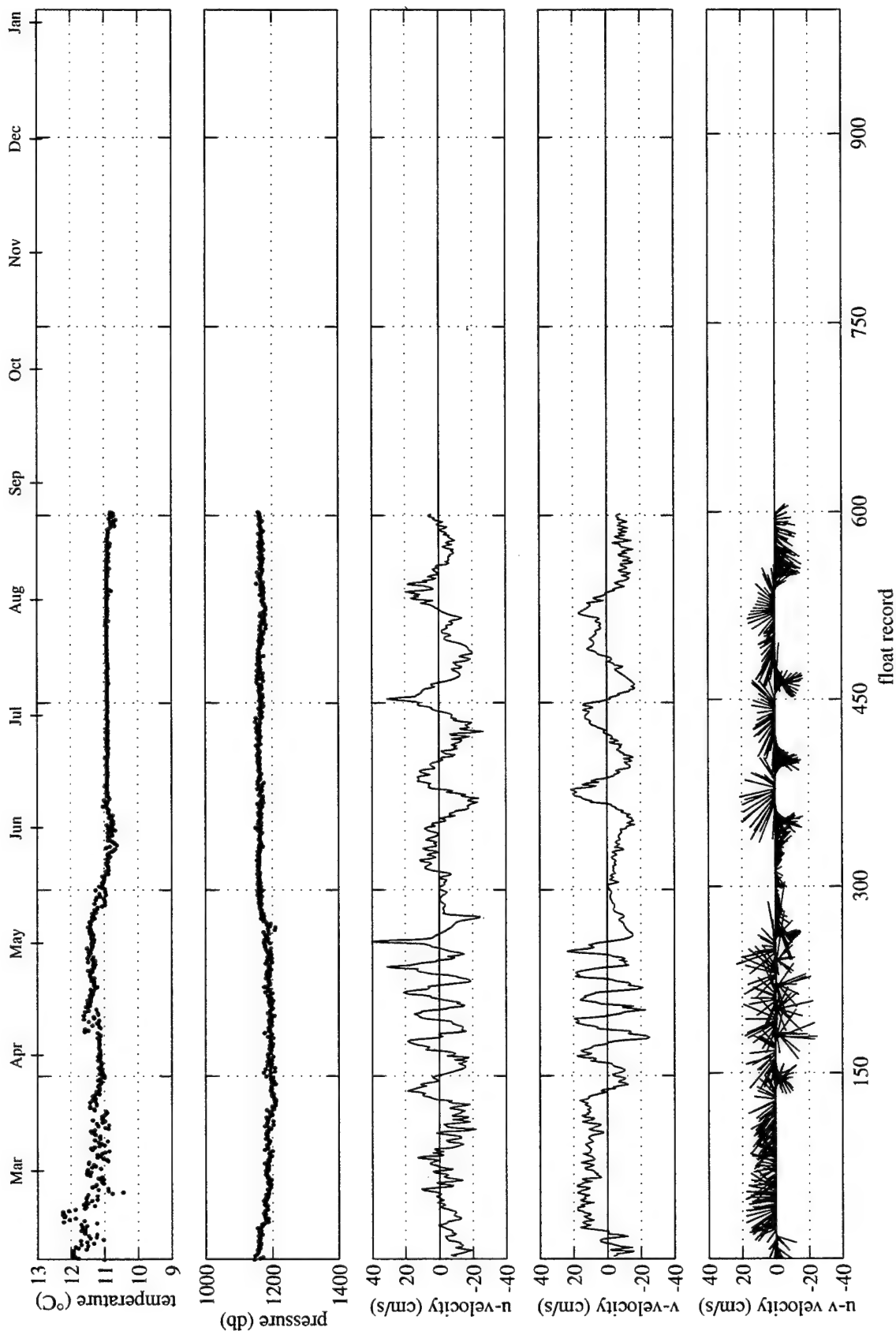


am126b

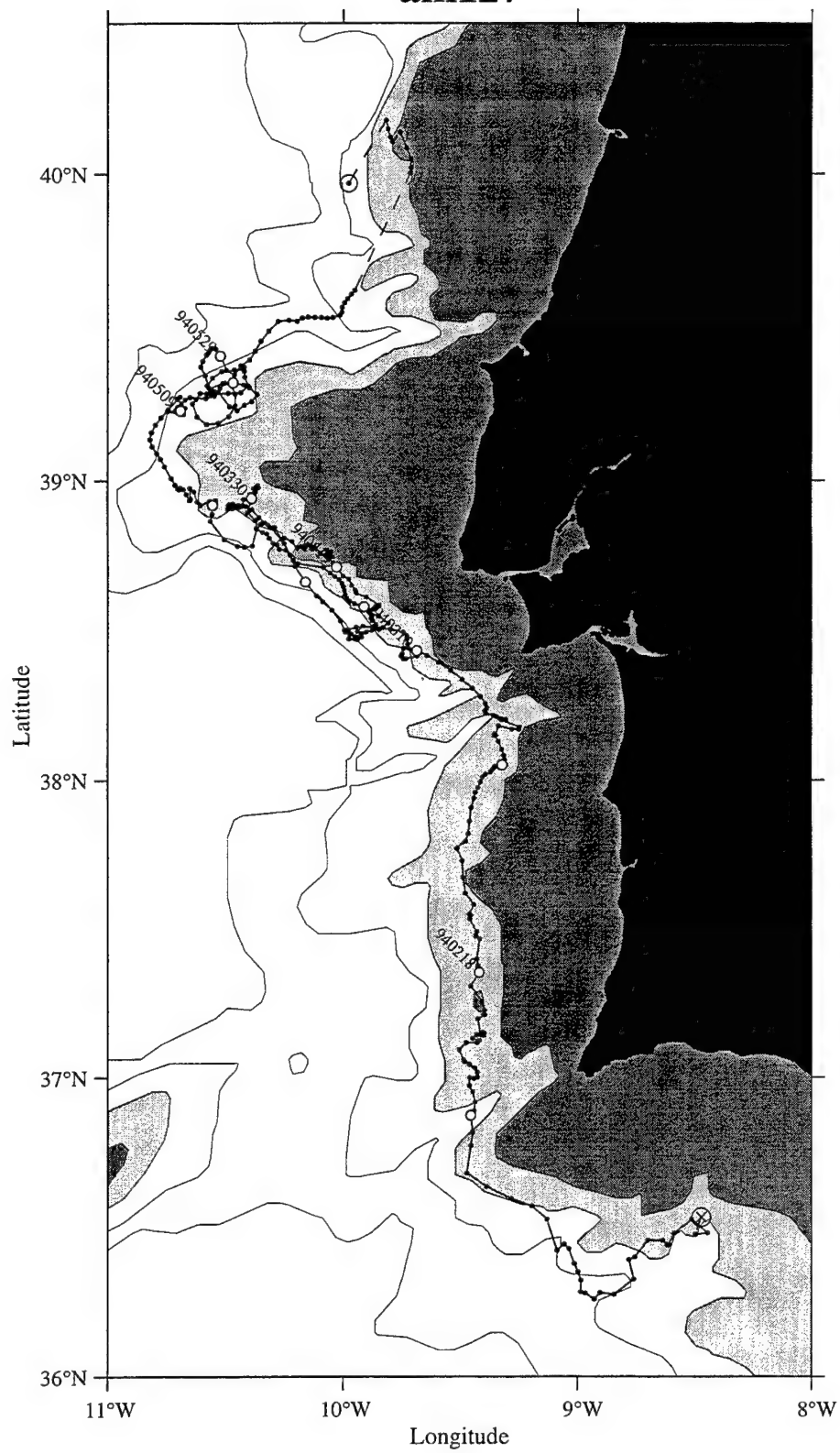


# am126b

1994



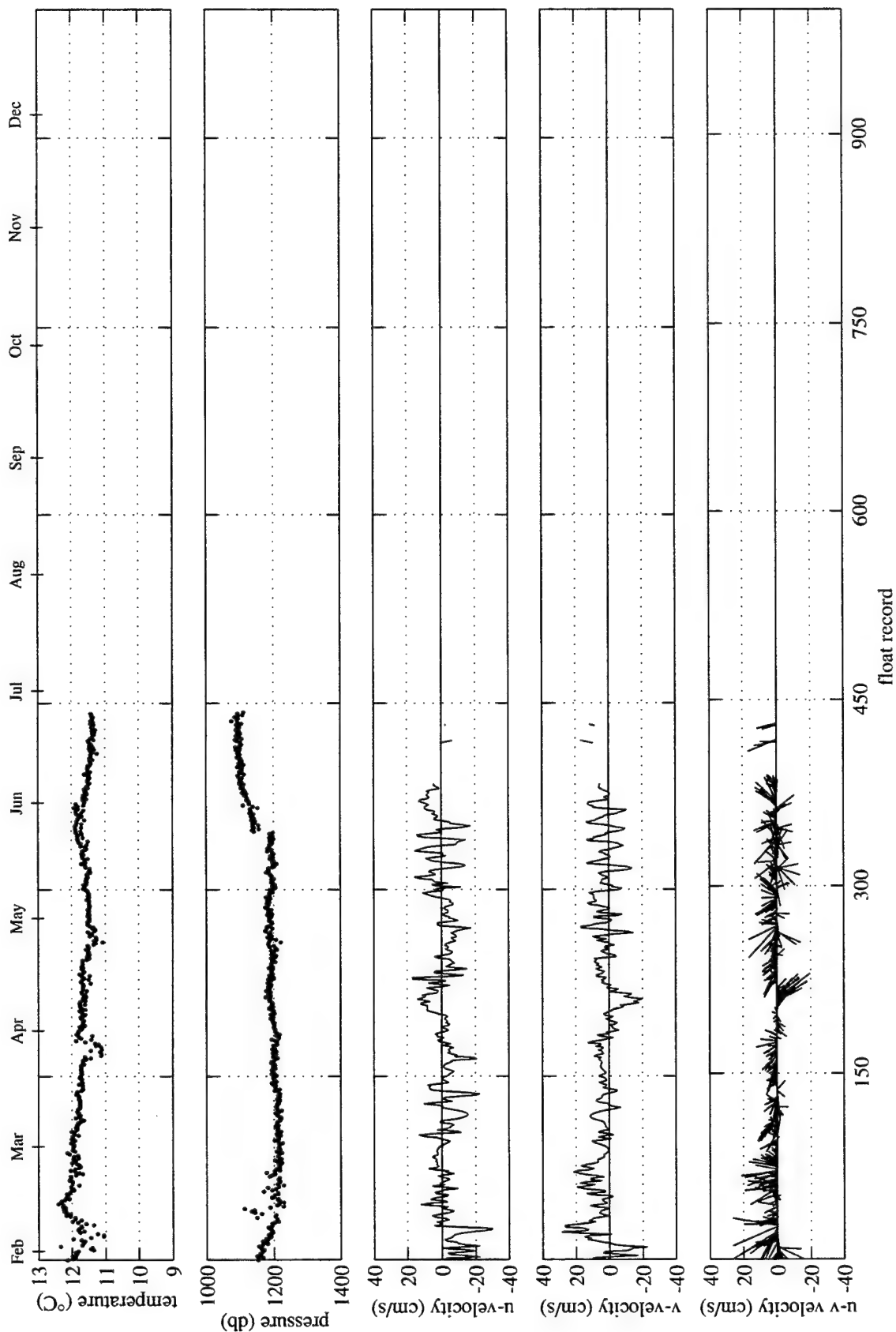
am127



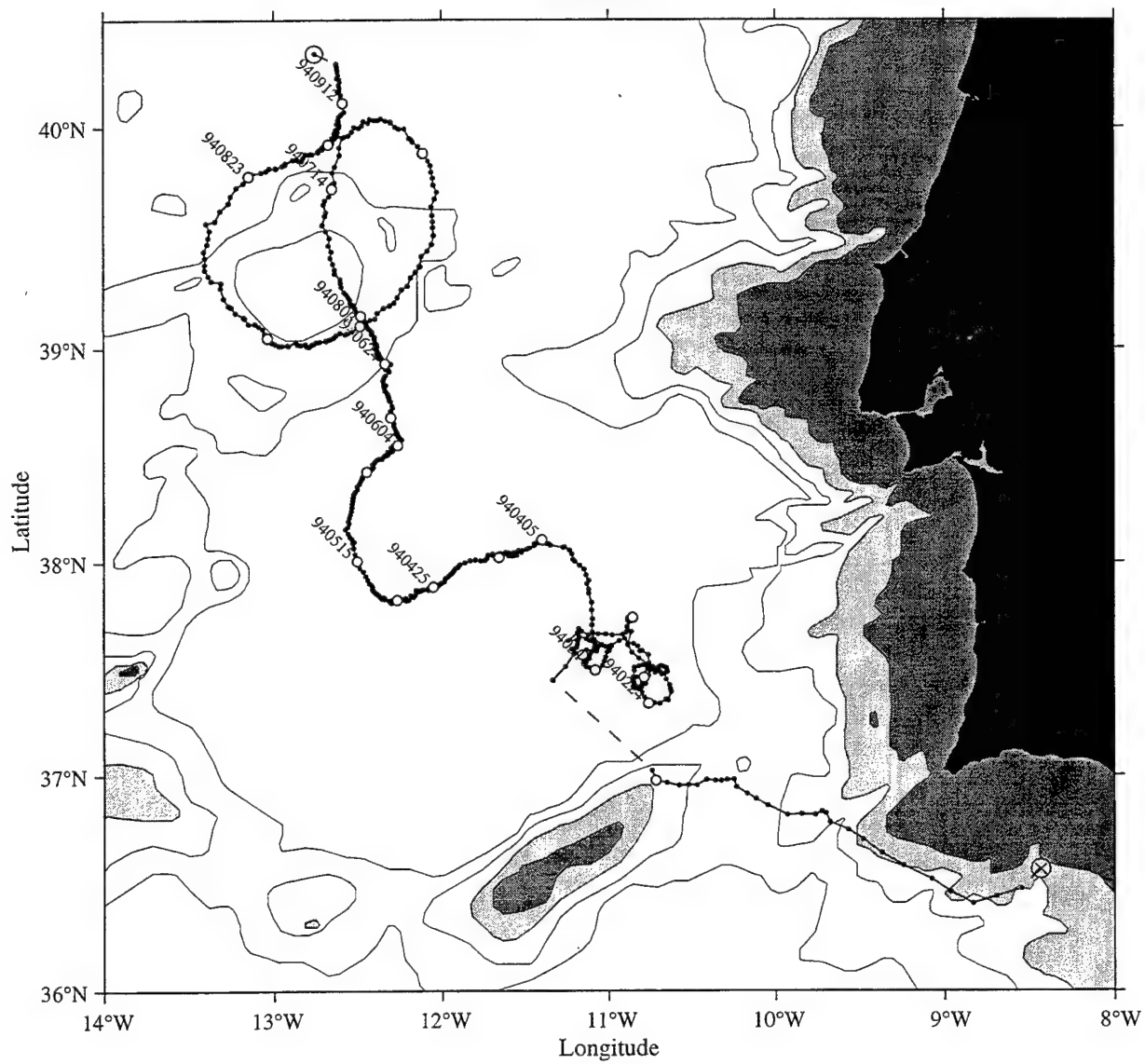


# am127

1994

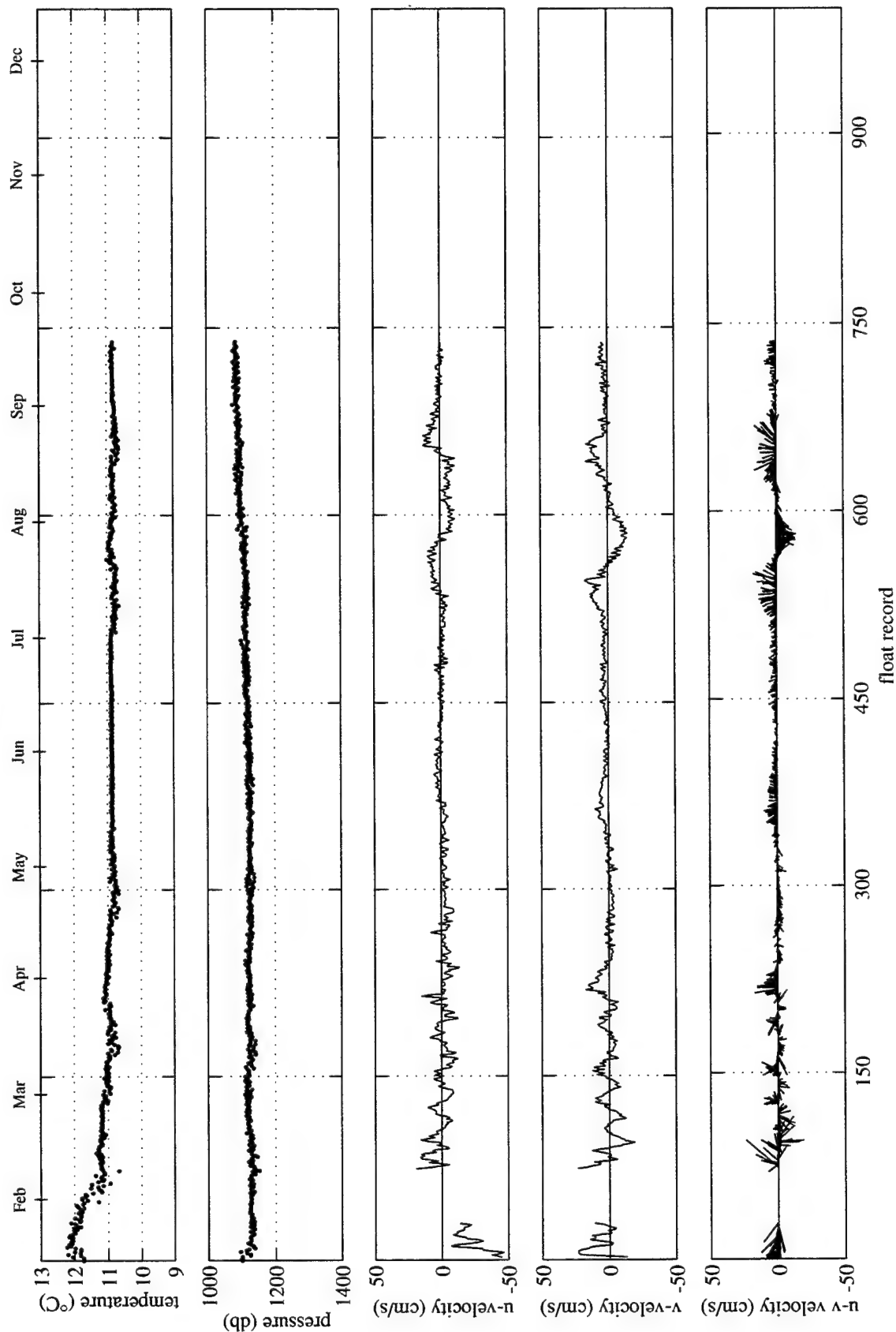


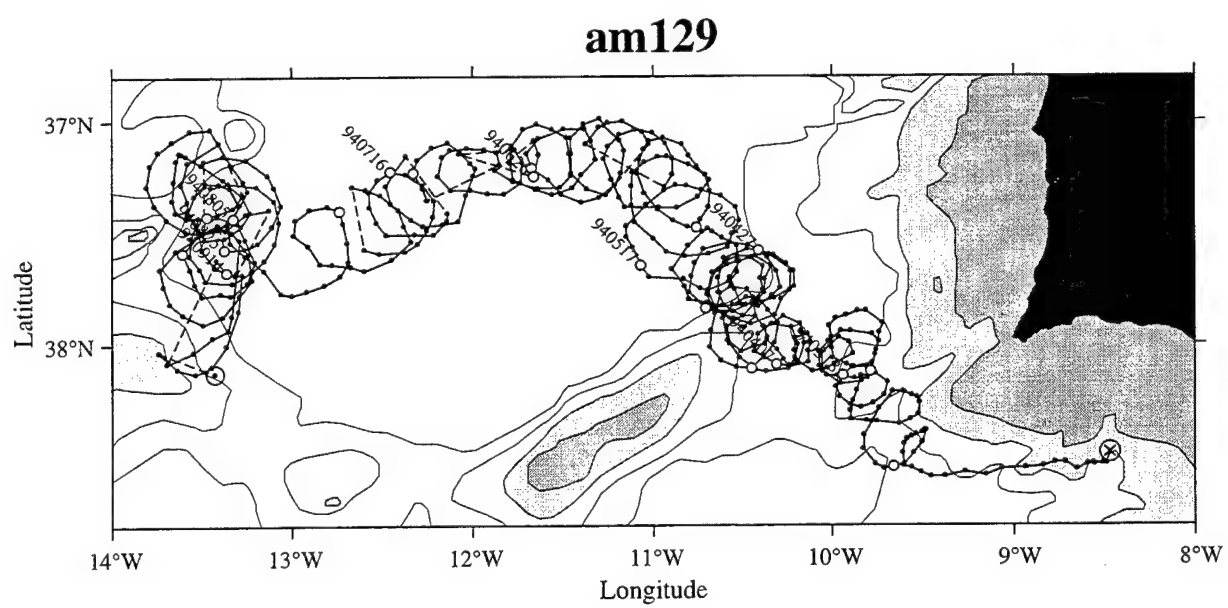
am128



# am128

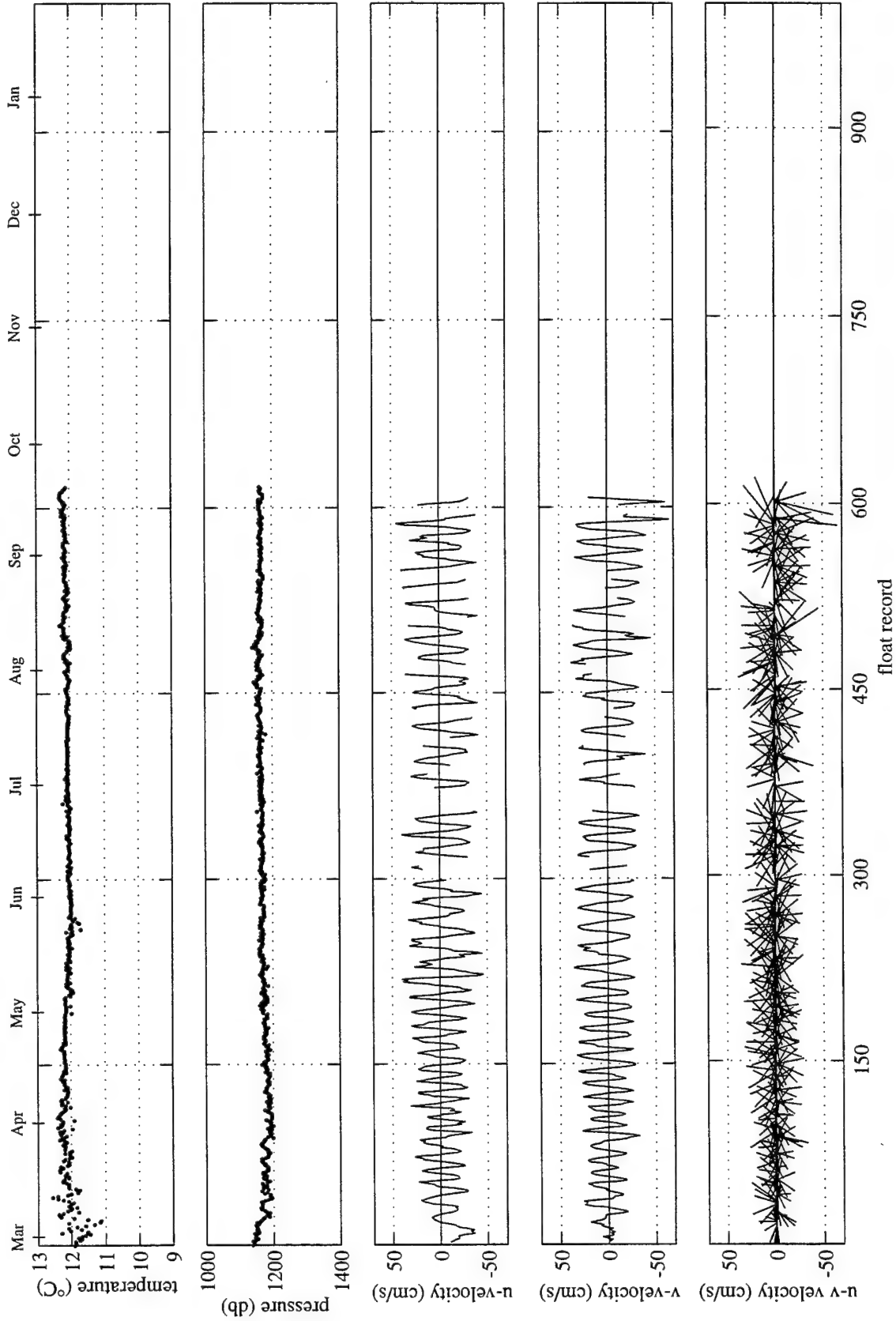
1994



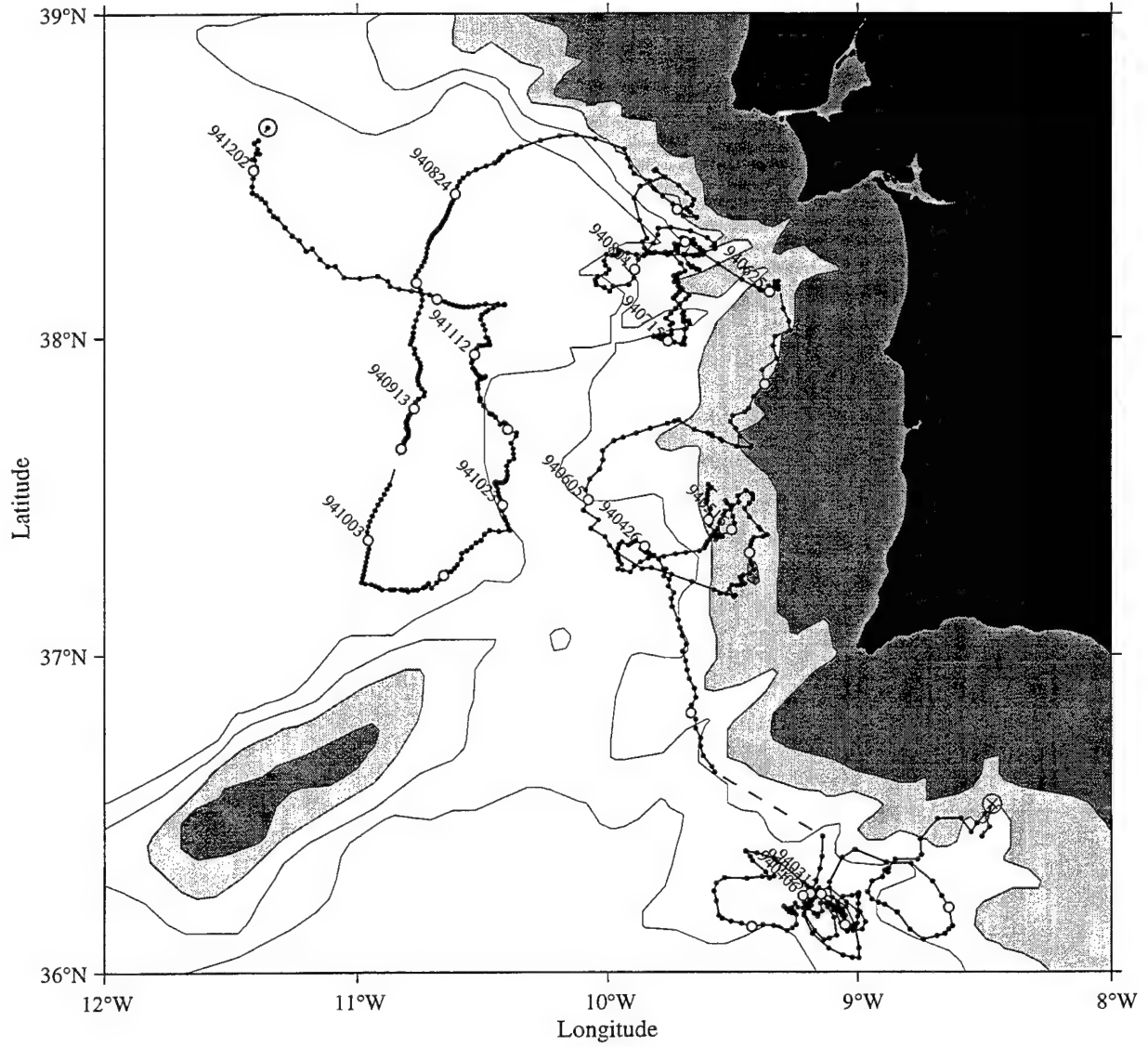


# am129

1994

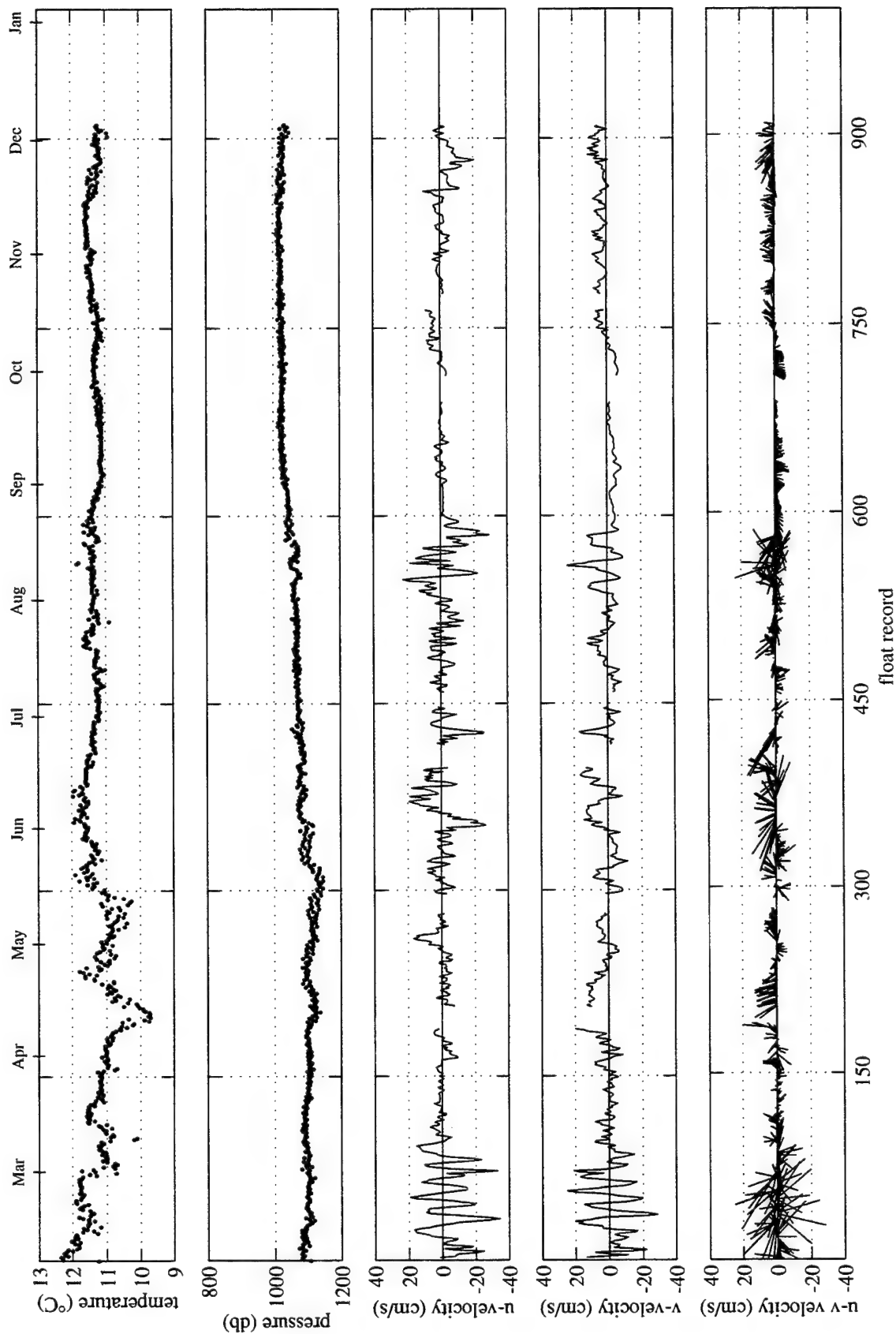


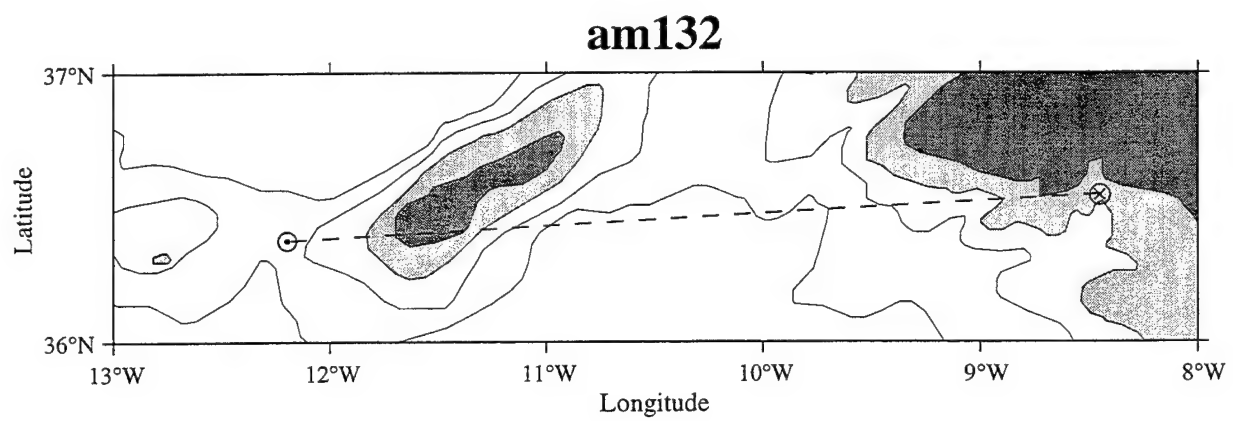
am130



# am130

1994

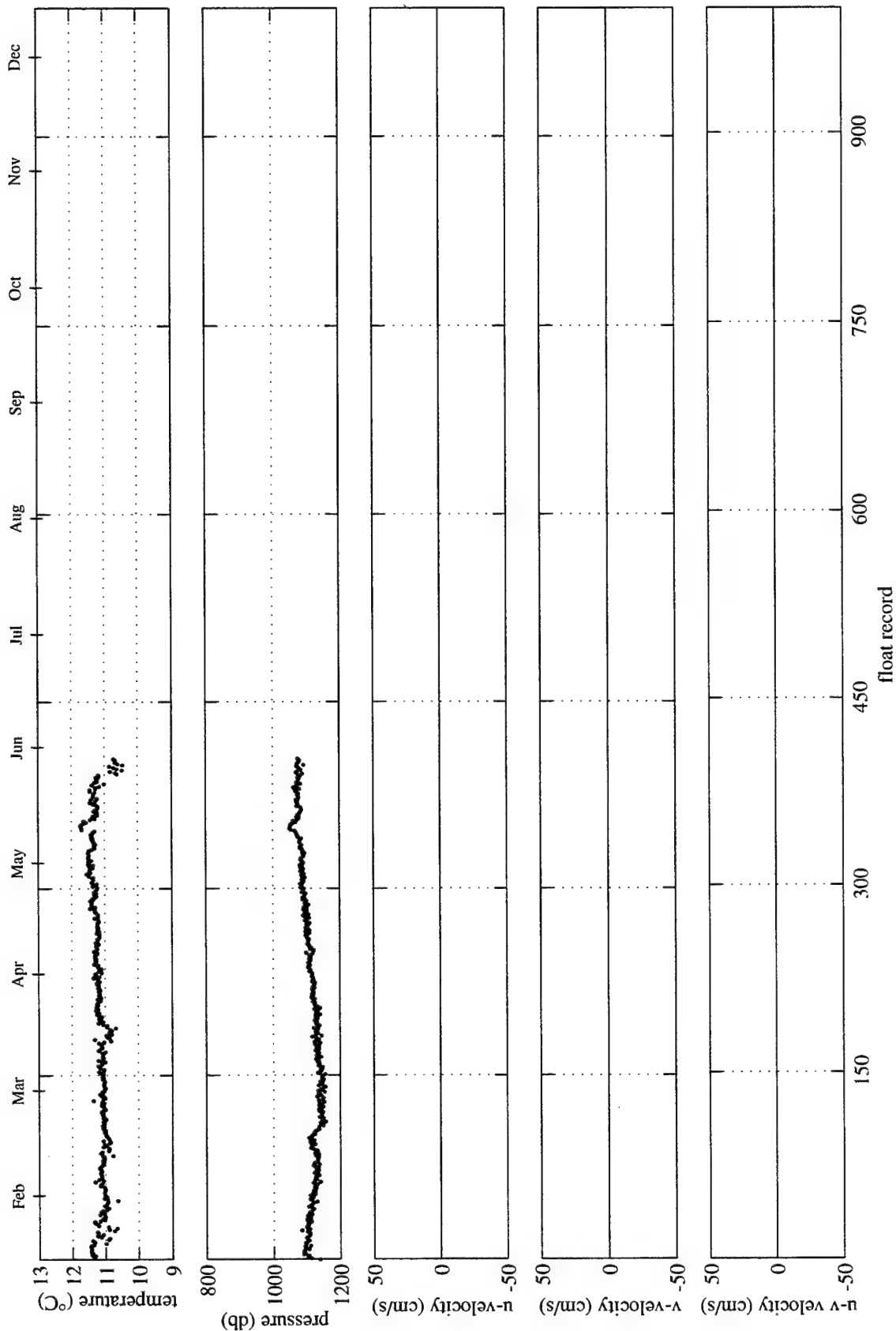




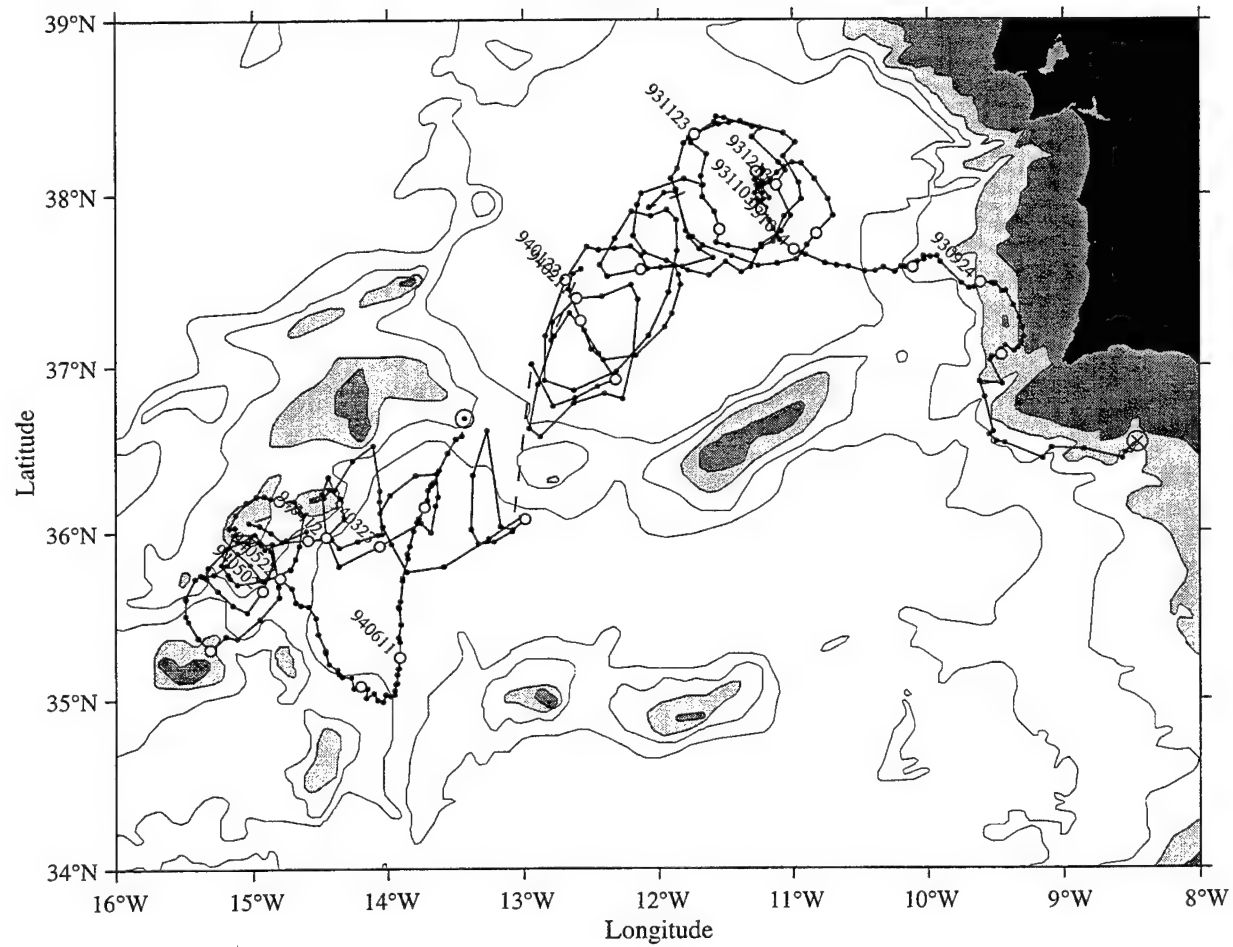


# am132

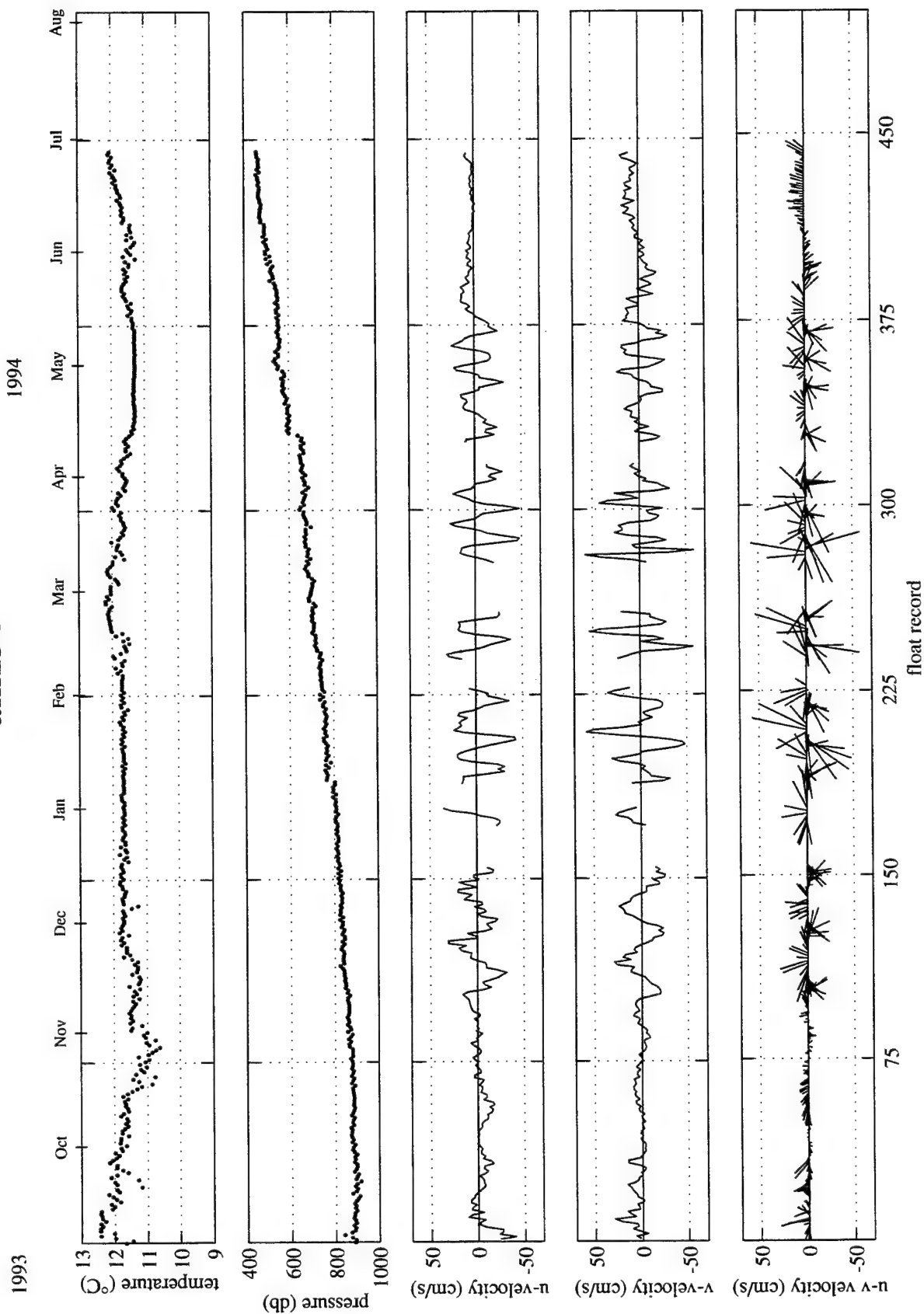
1994



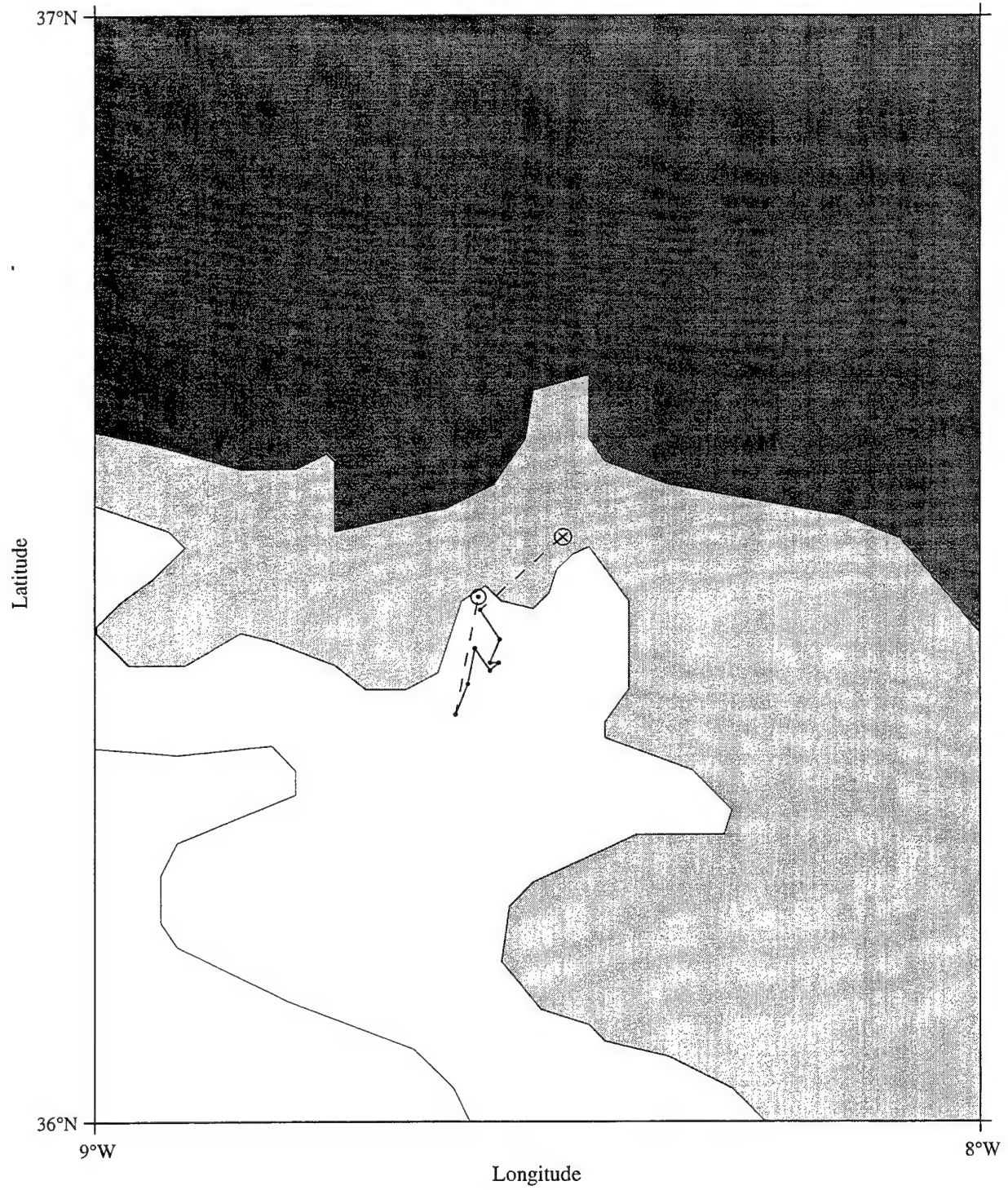
am134



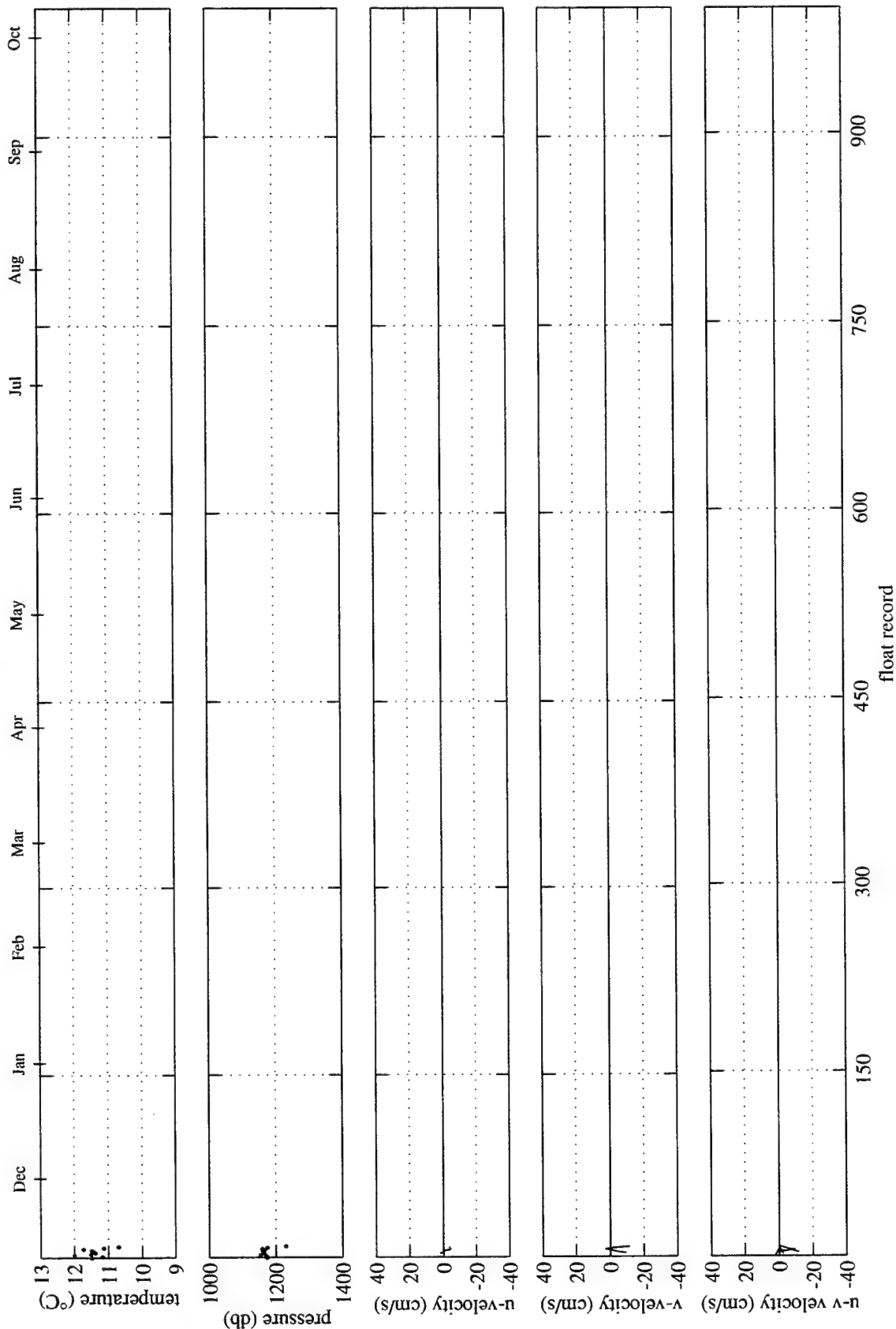
# am134



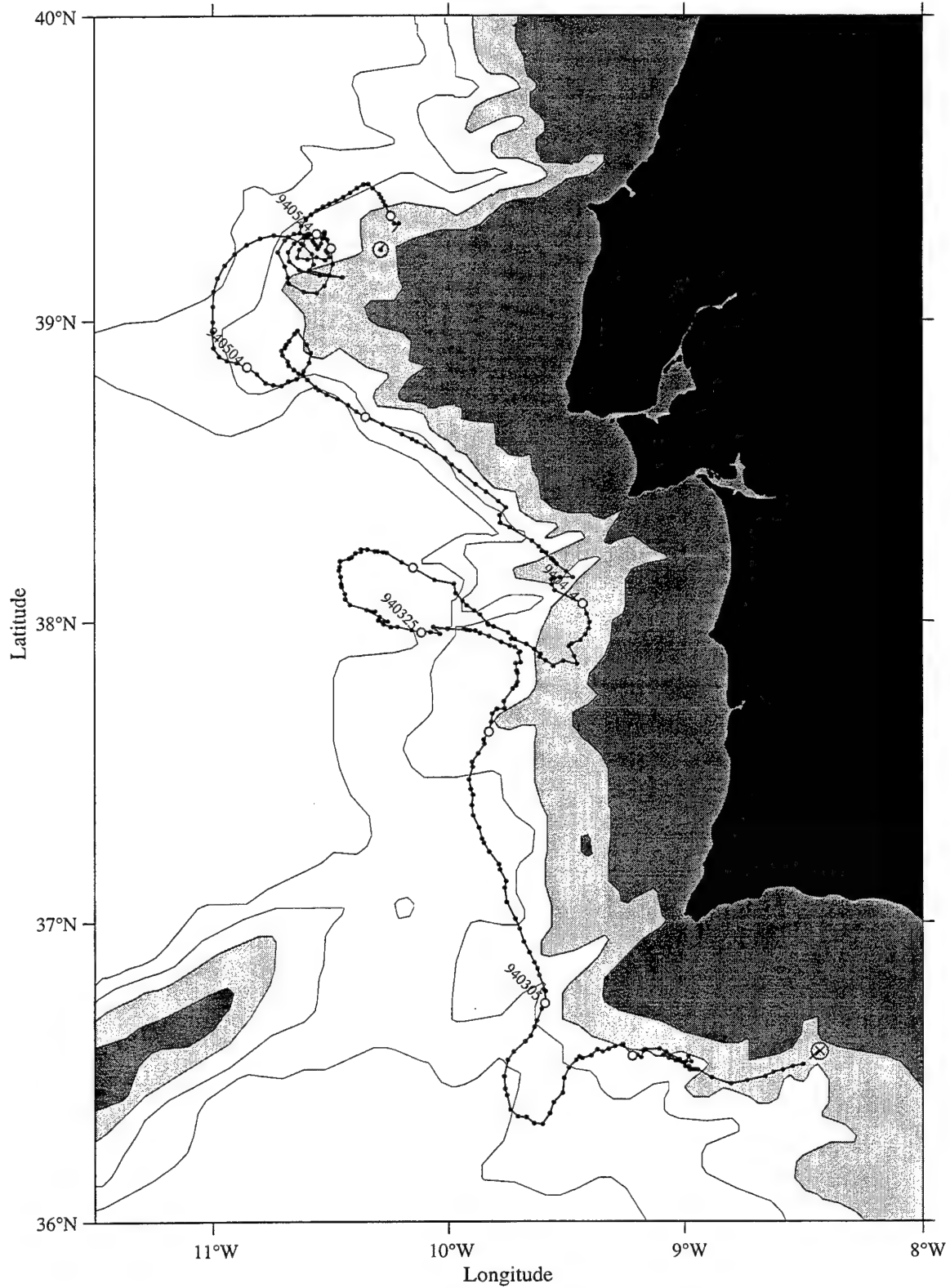
am135a



# am135a 1994

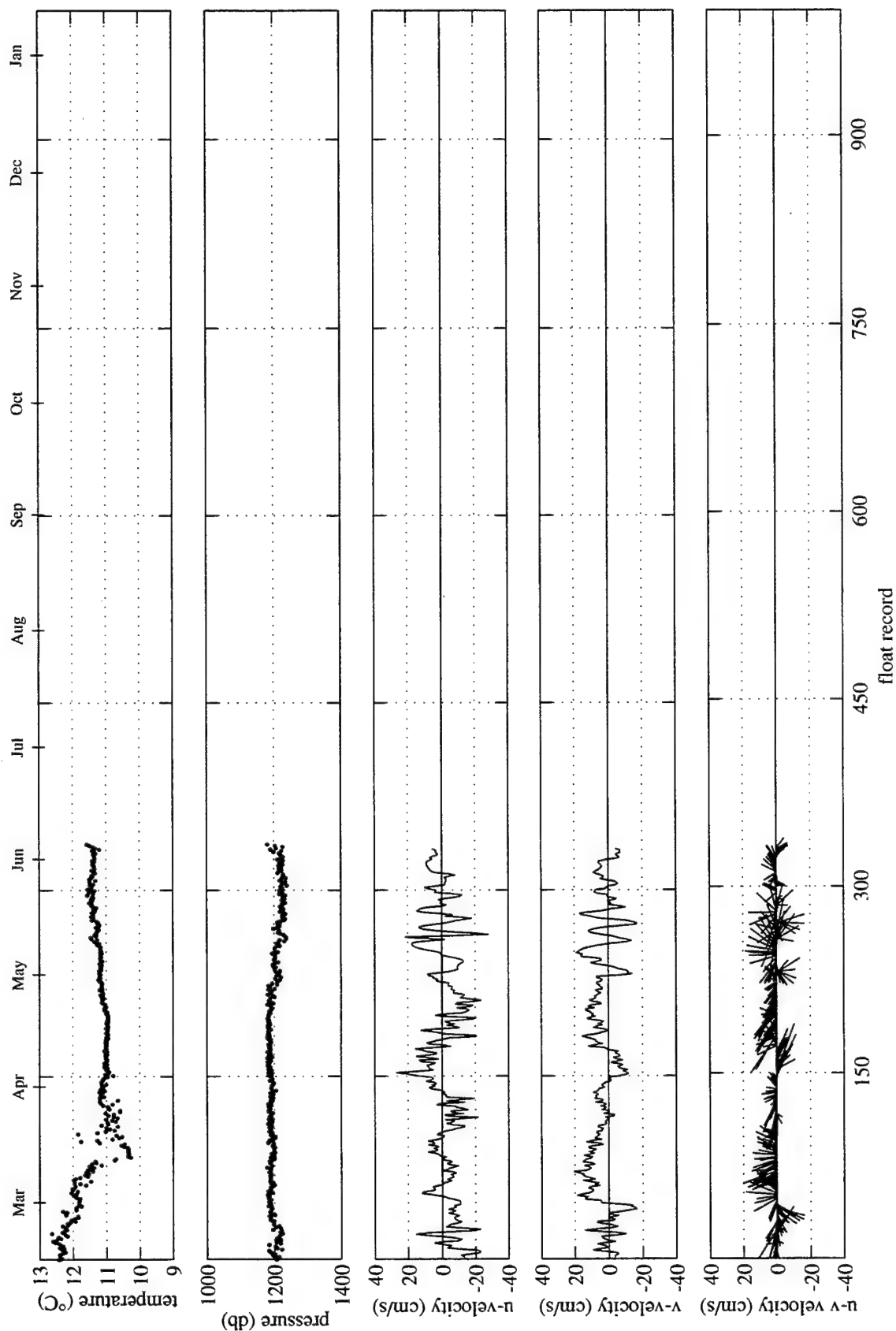


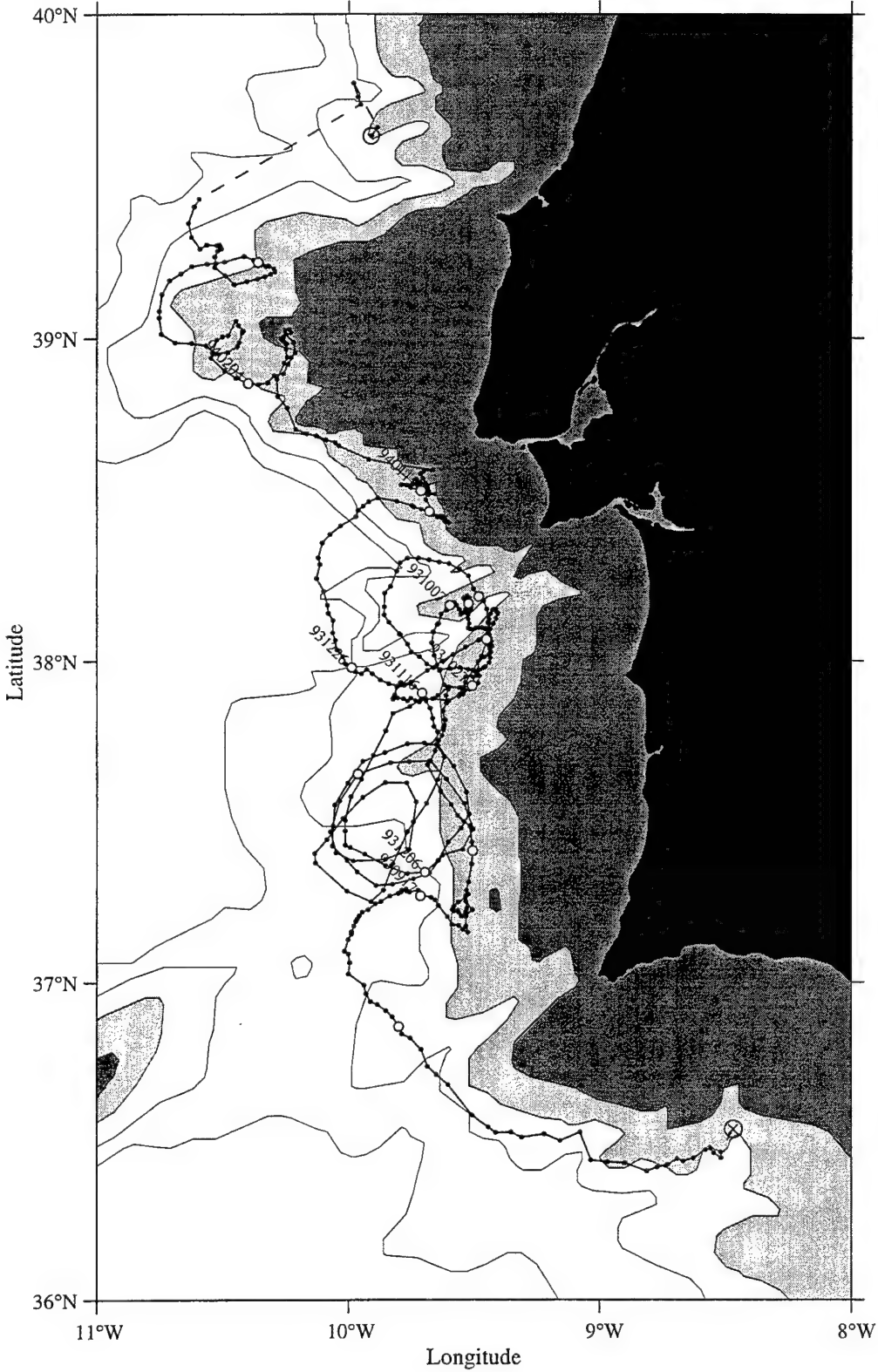
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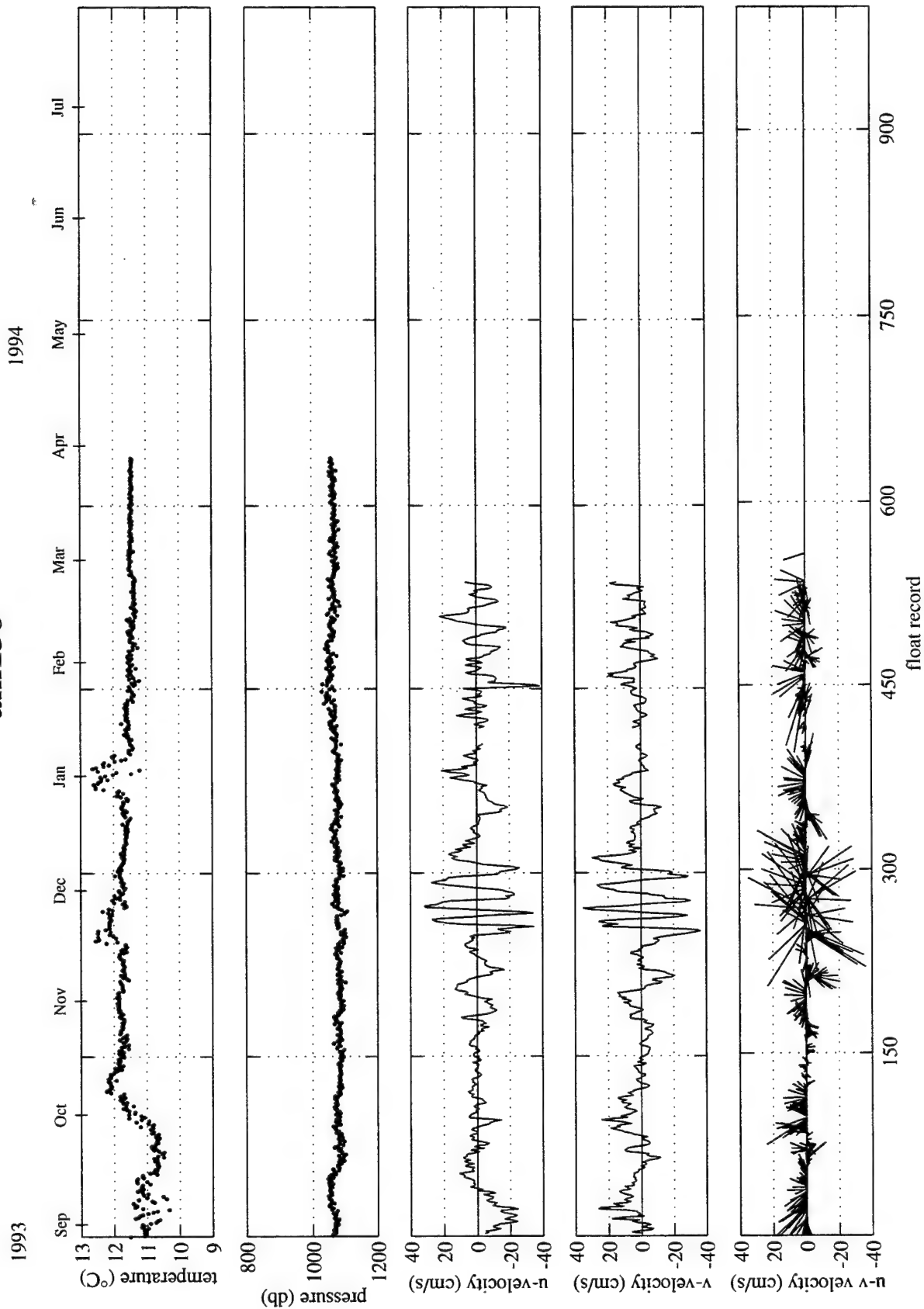
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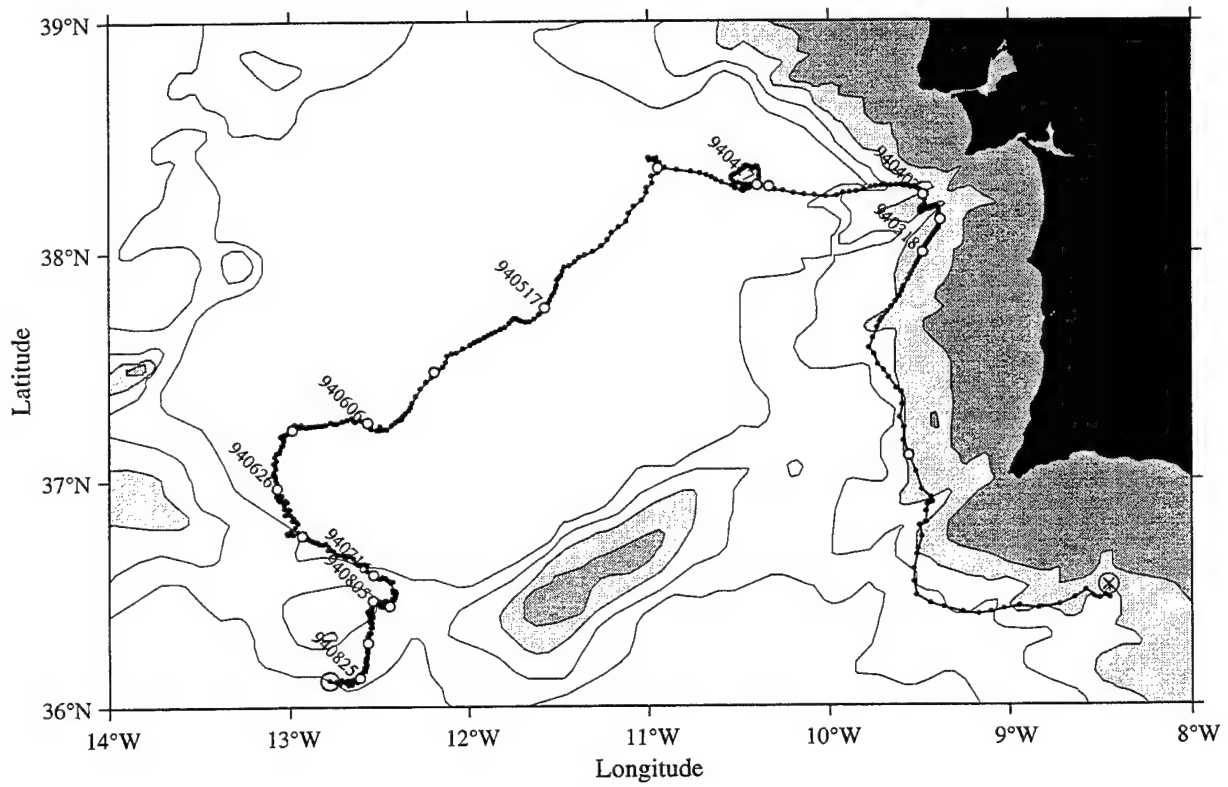
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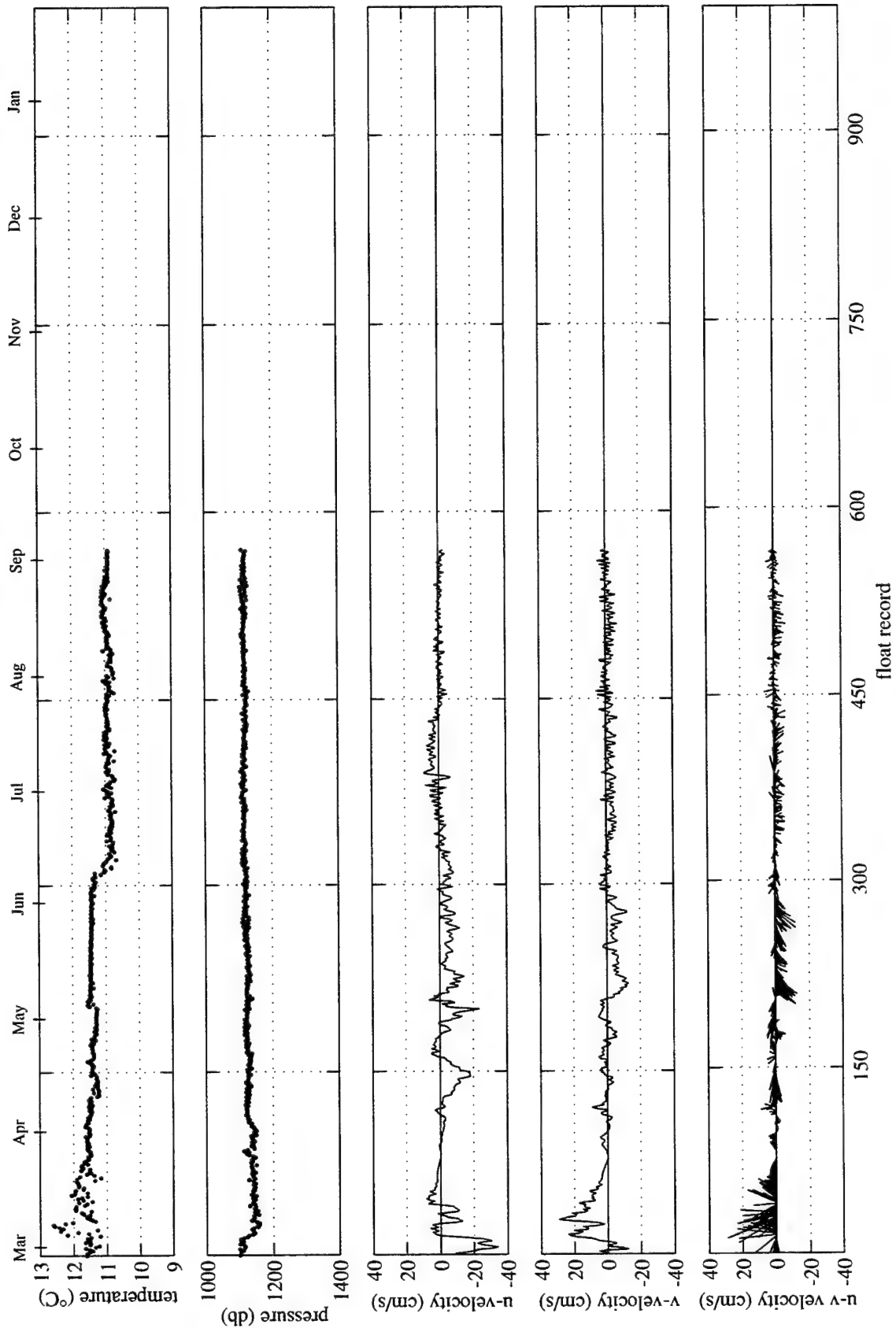


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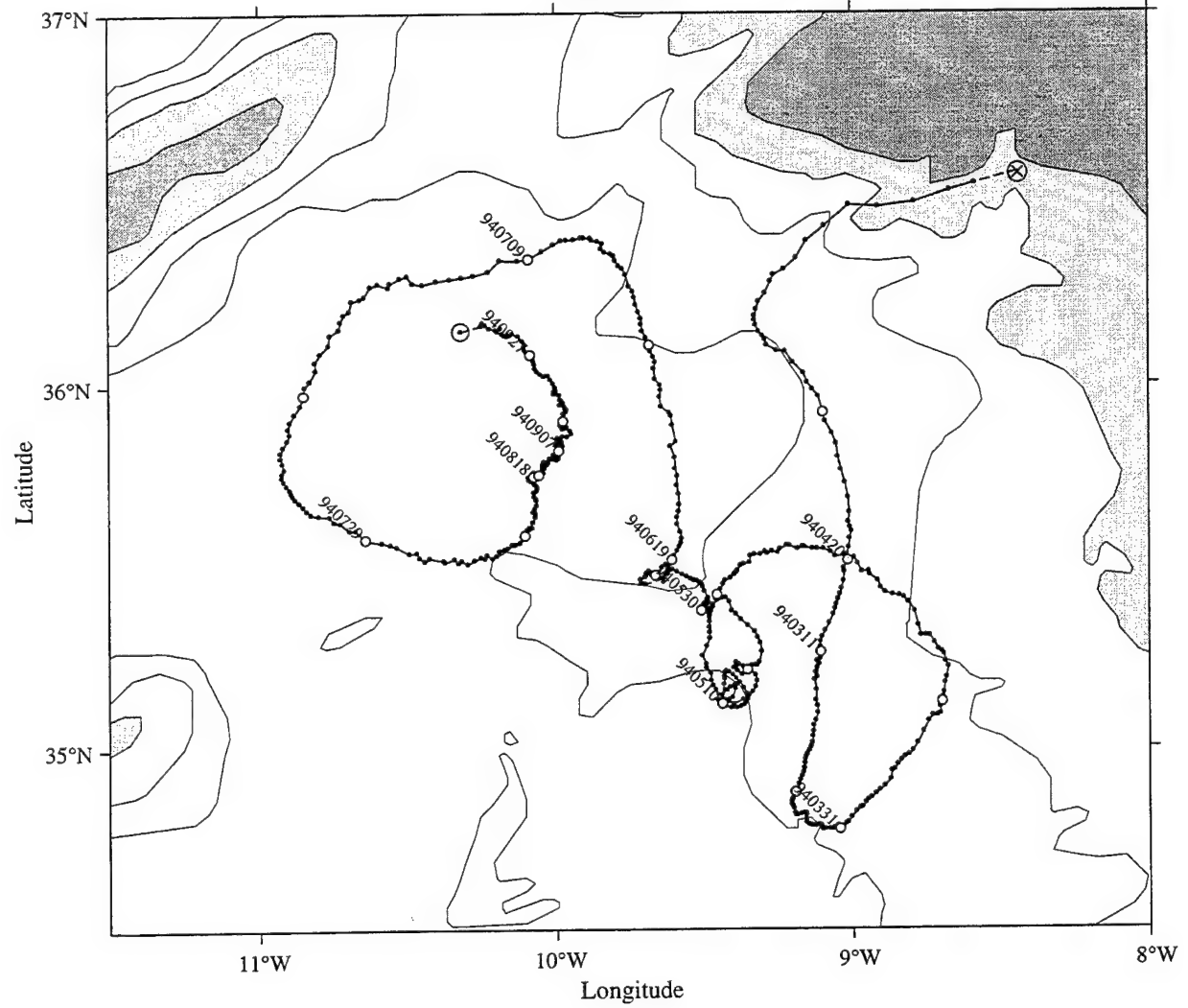


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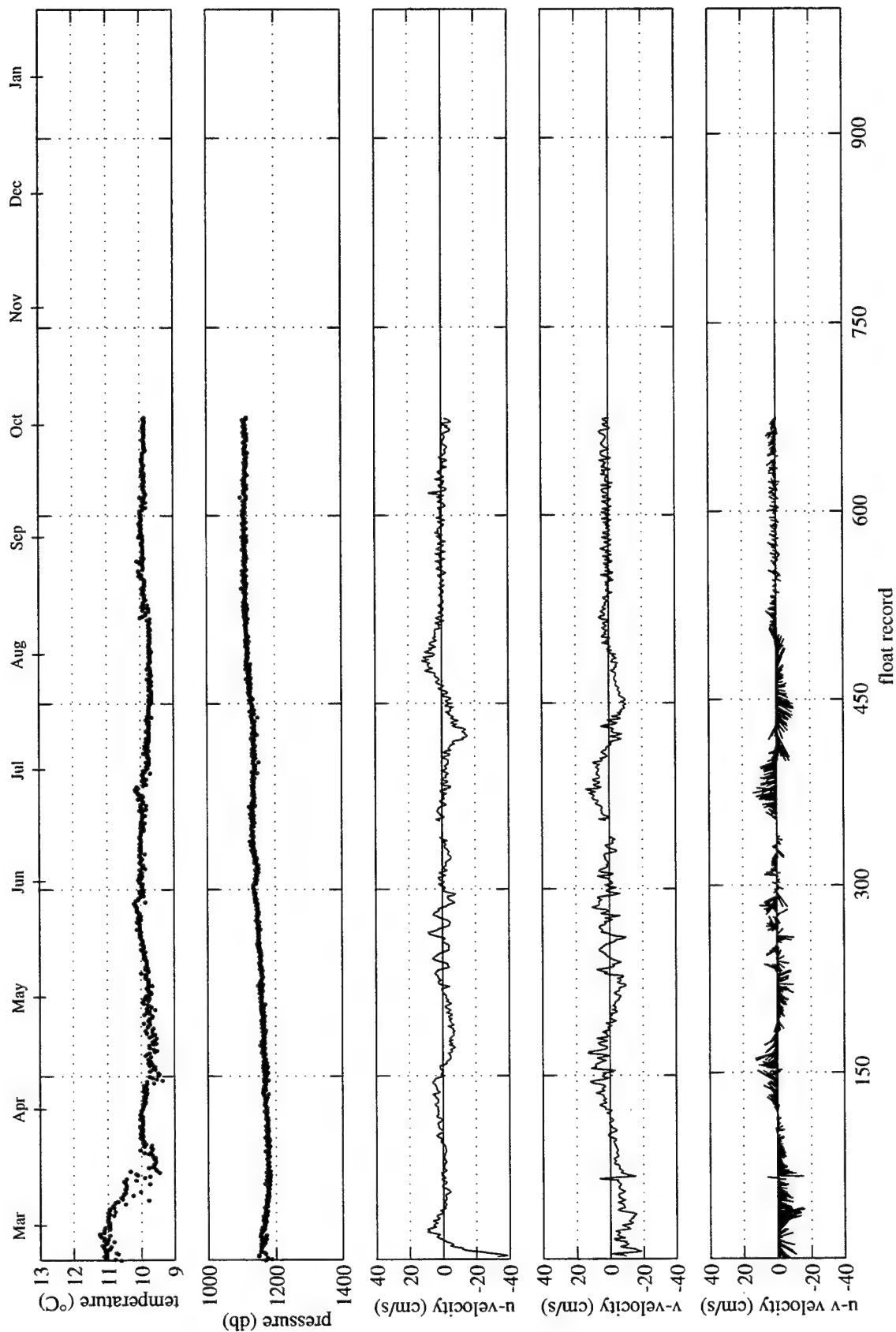


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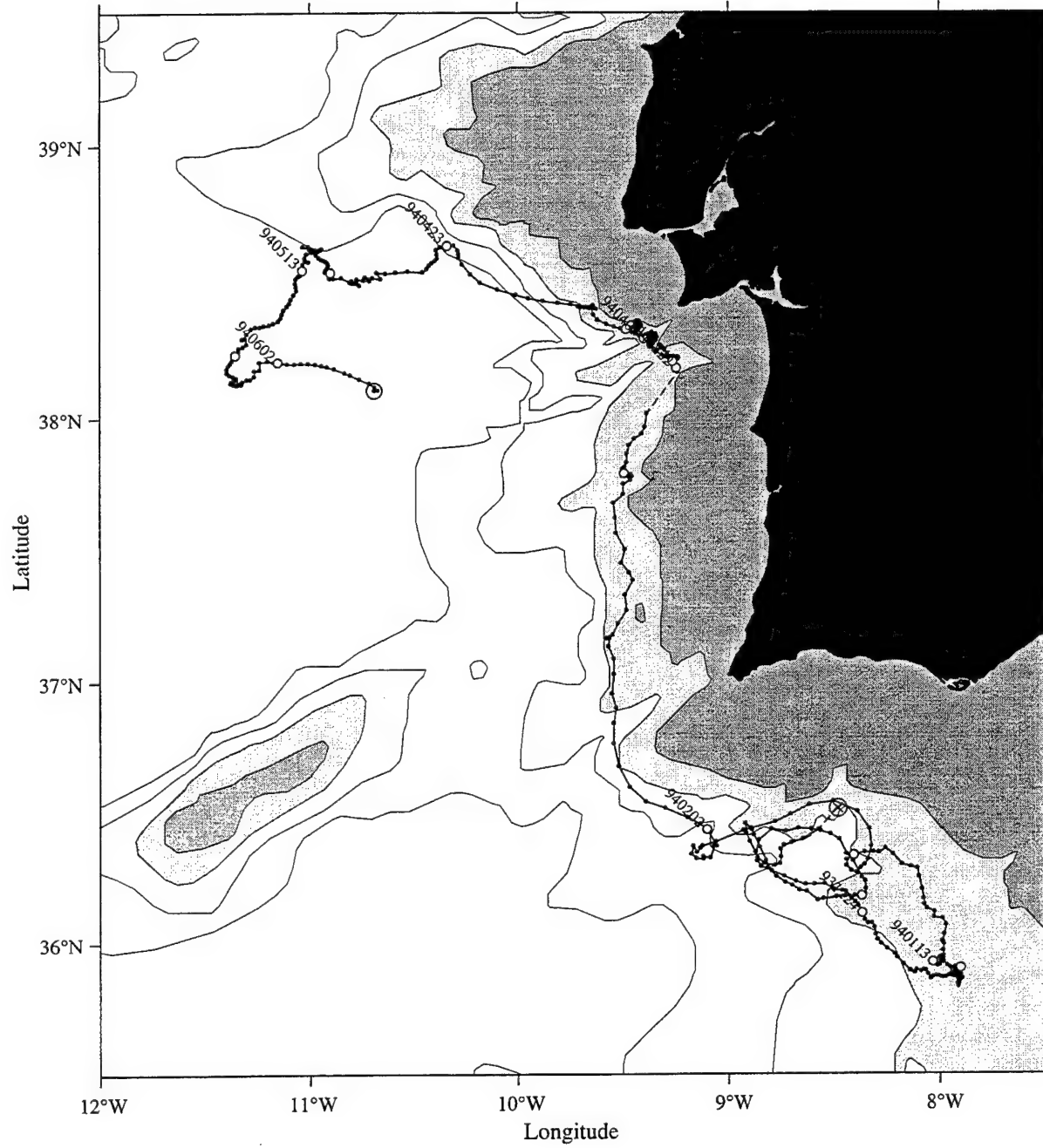


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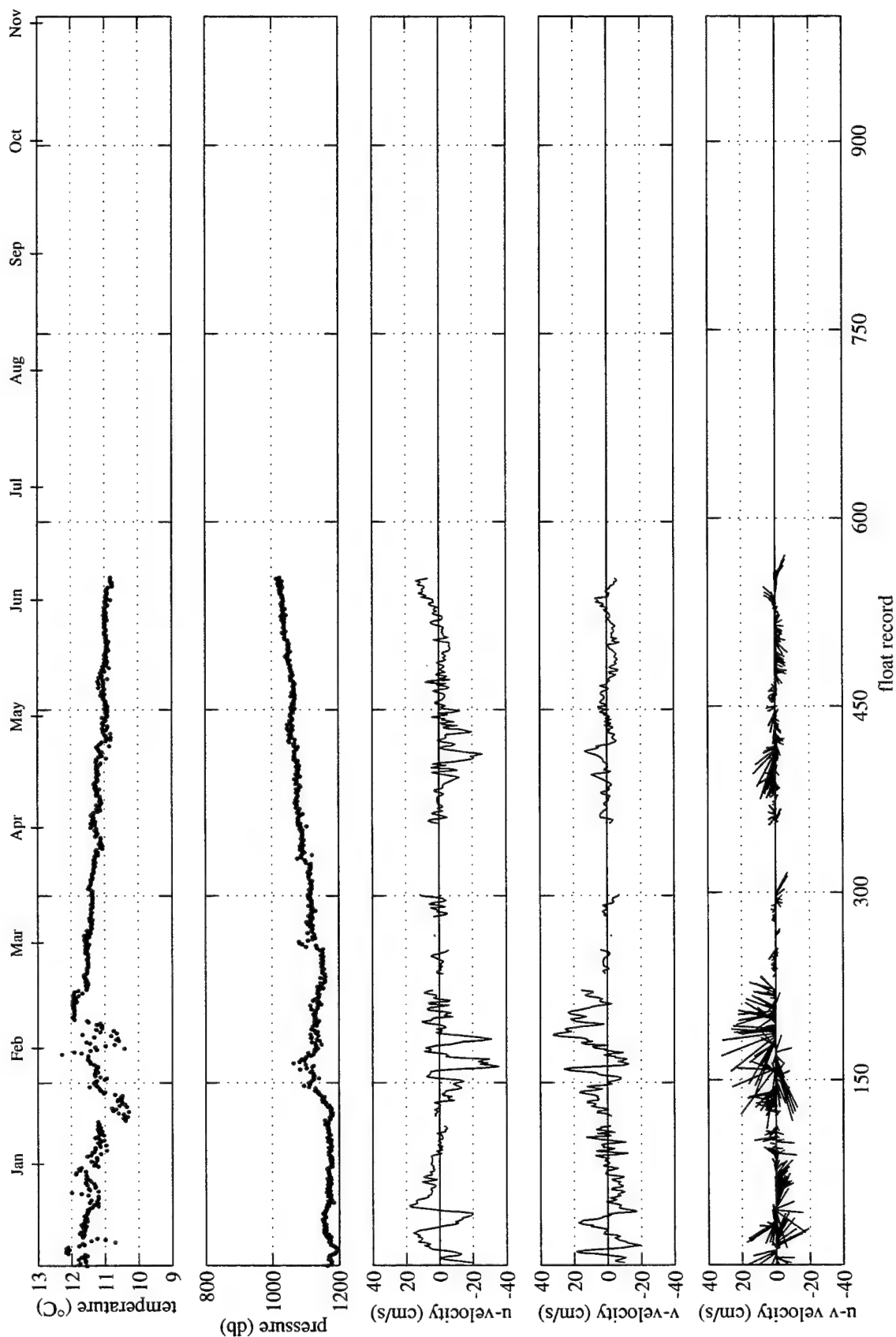
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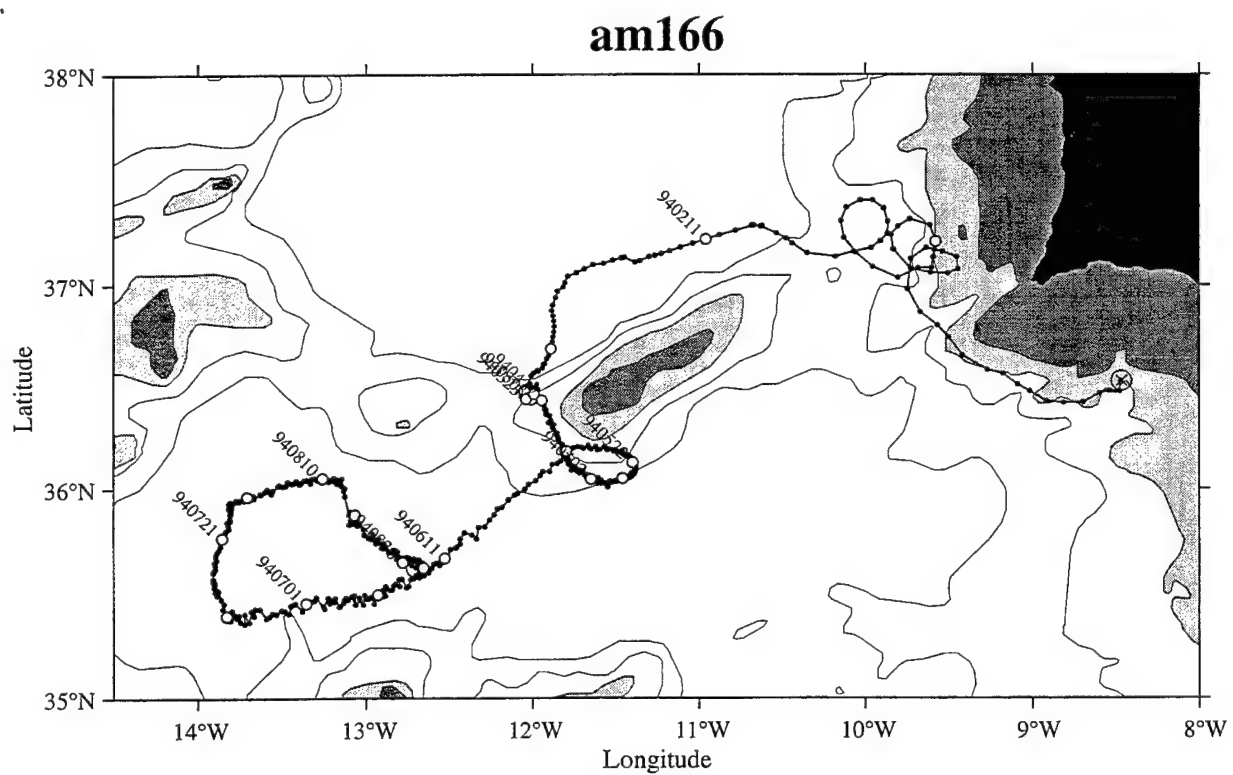


am165



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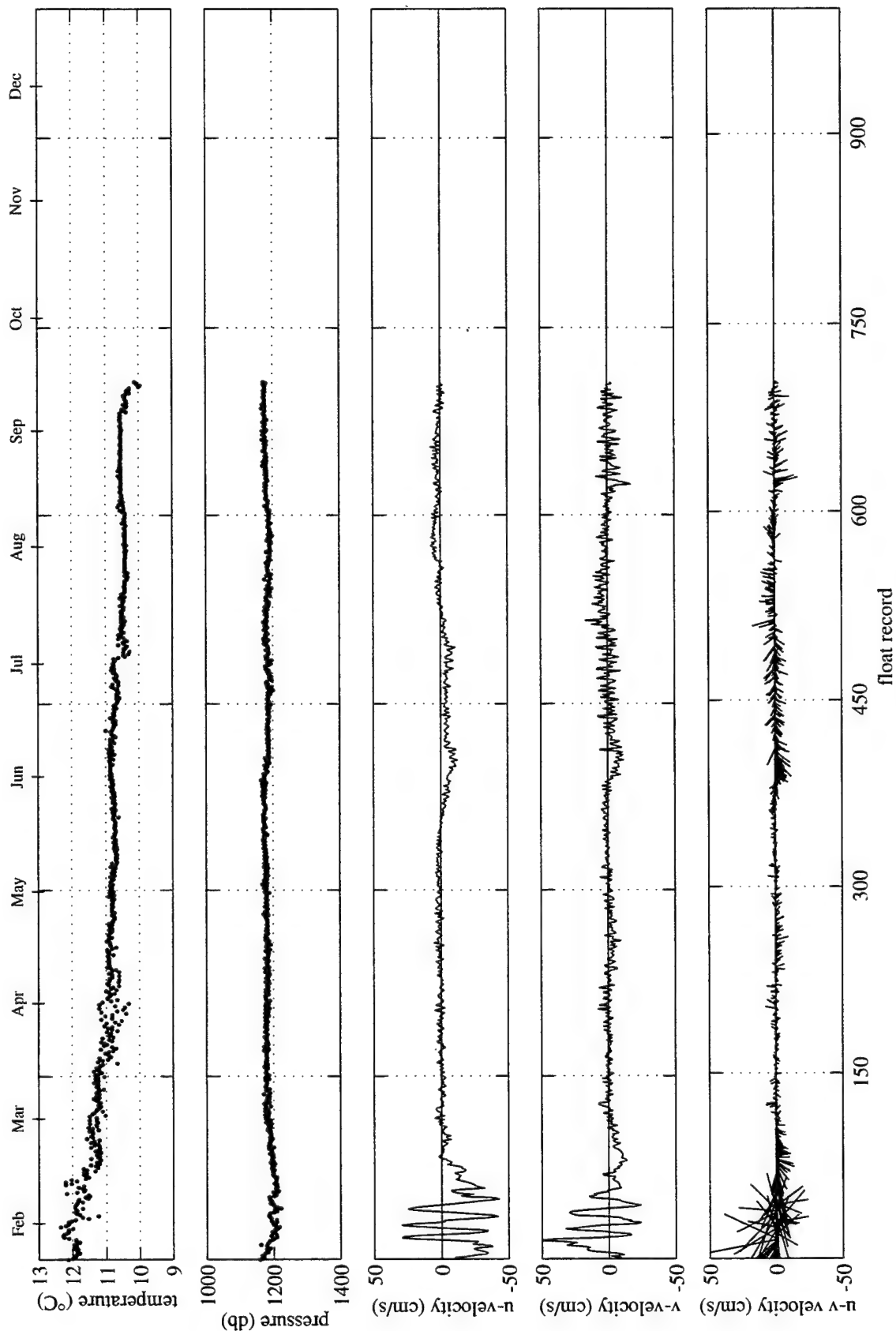




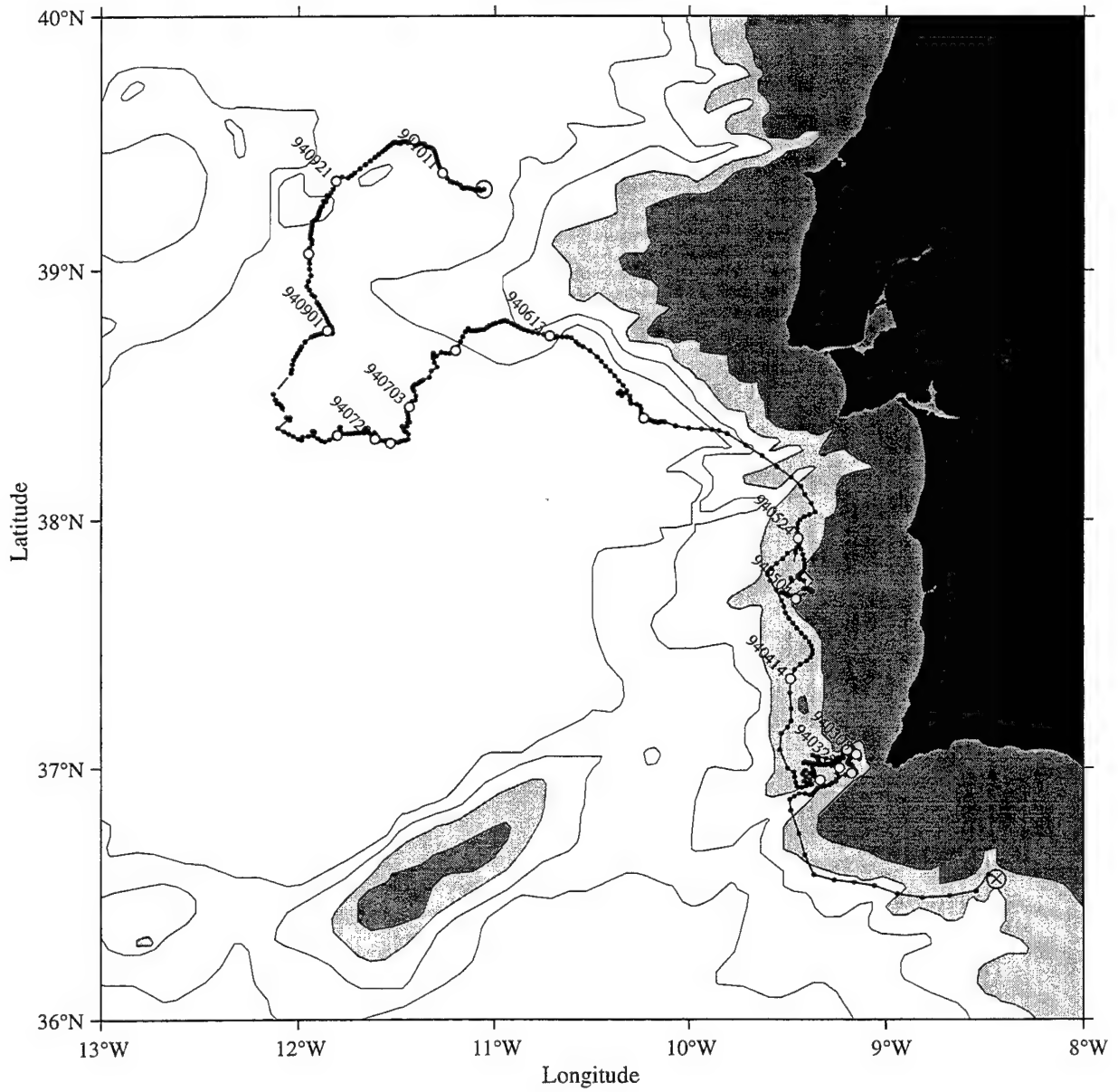


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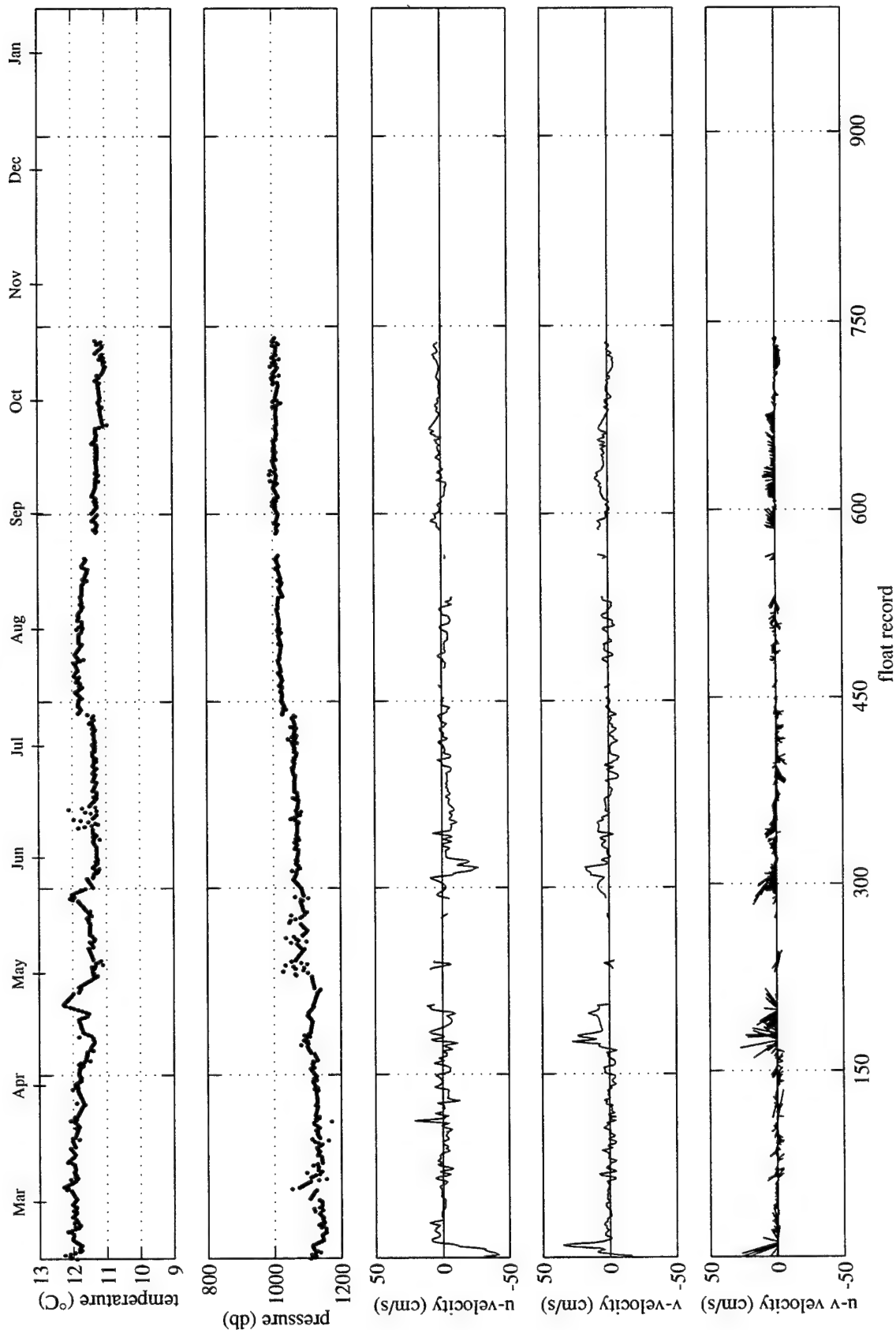


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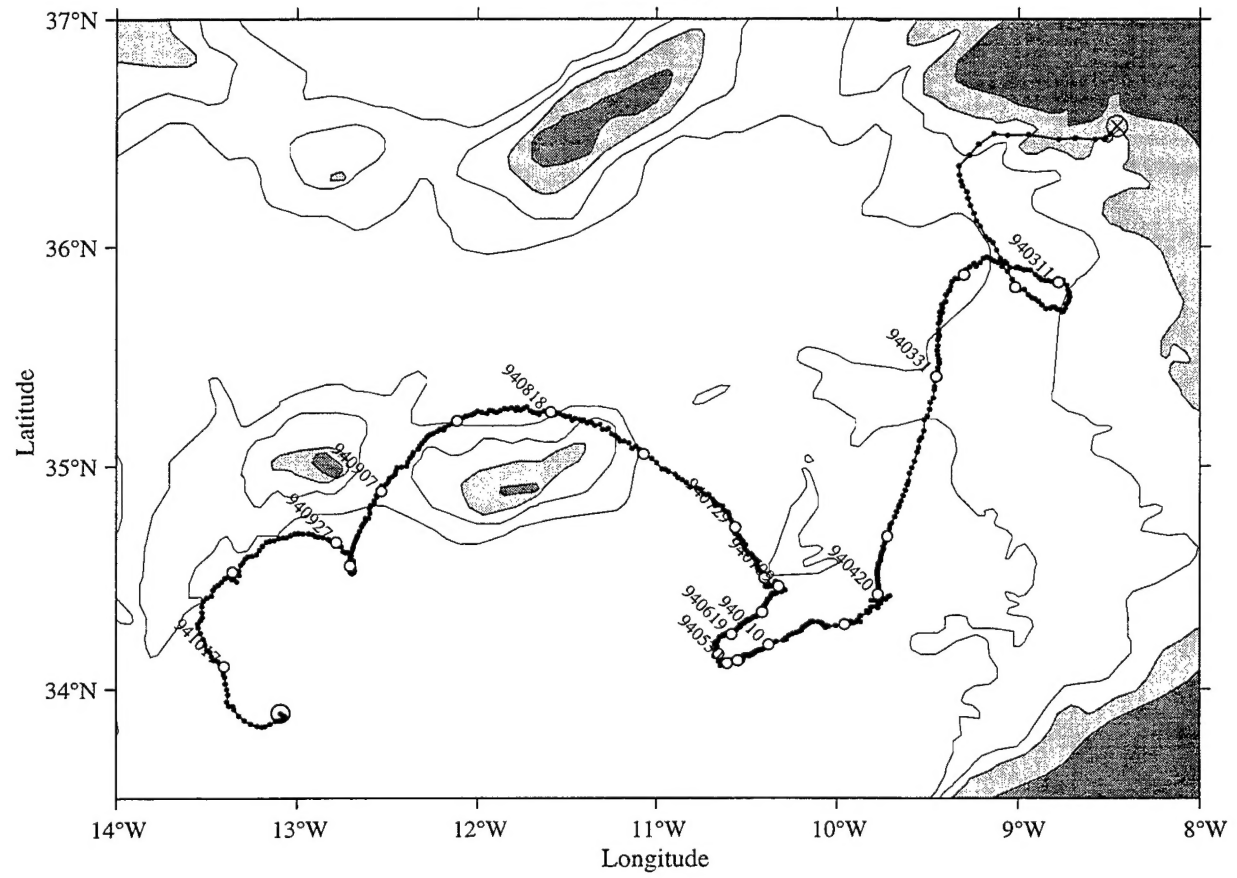


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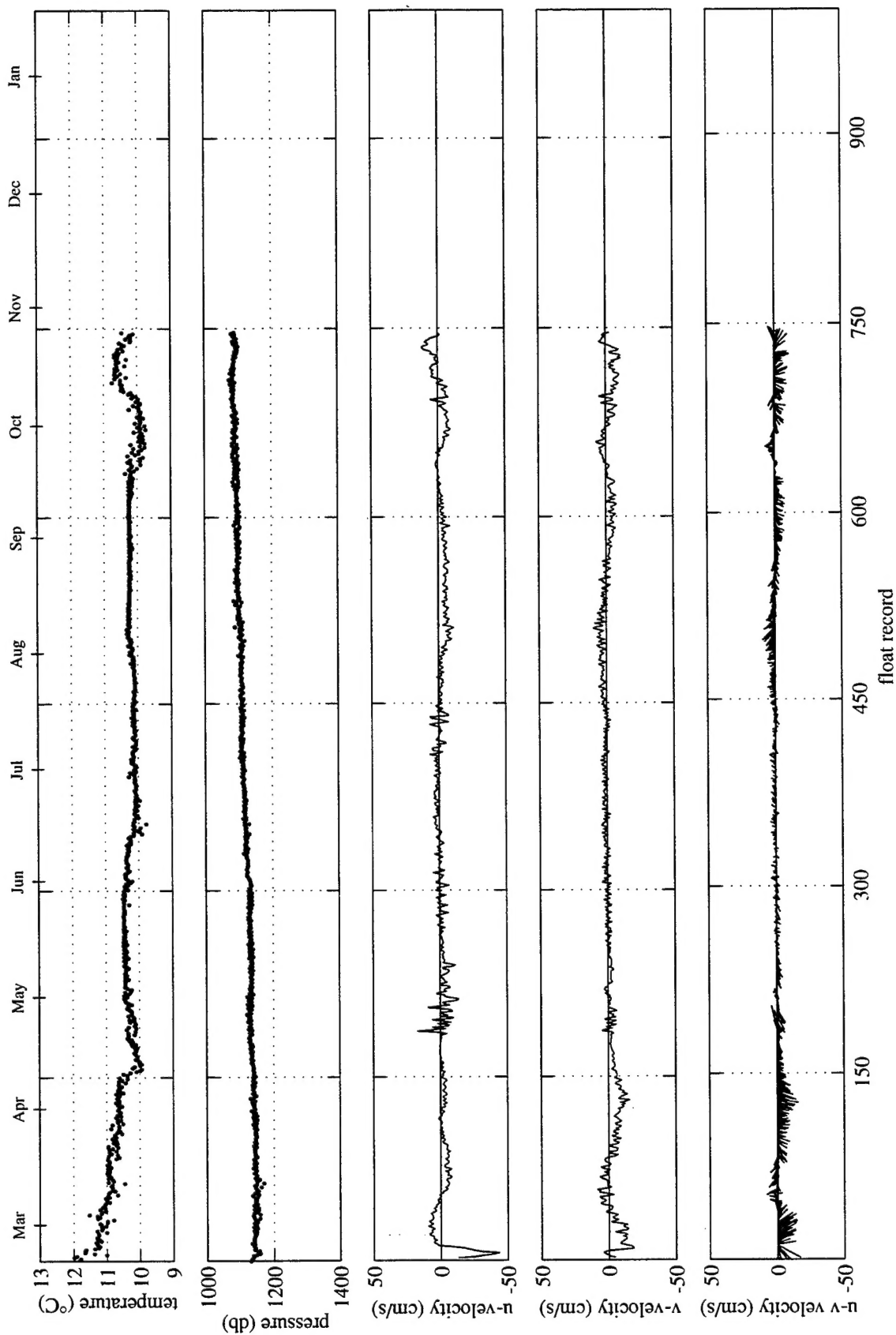


am169



# am169

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| <b>16. Abstract (Limit: 200 words)</b><br><br>This is the final data report of all acoustically tracked RAFOS data collected in 1993-1995 during A Mediterranean Undercurrent Seeding Experiment (AMUSE). The overall objective of the program was to observe directly the spreading pathways by which Mediterranean Water enters the North Atlantic. This includes the direct observation of Mediterranean eddies (meddies), which is one mechanism that transports Mediterranean Water to the North Atlantic. The experiment was comprised of a repeated high-resolution expendable bathythermograph (XBT) section and RAFOS float deployments across the Mediterranean Undercurrent south of Portugal near 8.5°W. A total of 49 floats were deployed at a rate of about two floats per week on 23 cruises on the chartered Portuguese-based vessel, Kialoa II, and one cruise on the R/V Endeavor. The floats were ballasted for 1100 or 1200 decibars (db) to seed the lower salinity core of the Mediterranean Undercurrent. The objectives of the Lagrangian float study were (1) to identify where meddies form, (2) to make the first direct estimate of meddy formation frequency, (3) to estimate the fraction of time meddies are being formed, and (4) to determine the pathways by which Mediterranean Water which is not trapped in meddies enters the North Atlantic. |                                    |  |  |
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| <b>b. Identifiers/Open-Ended Terms</b>   |                                    |  |  |
| <b>c. COSATI Field/Group</b>   |                                    |  |  |
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